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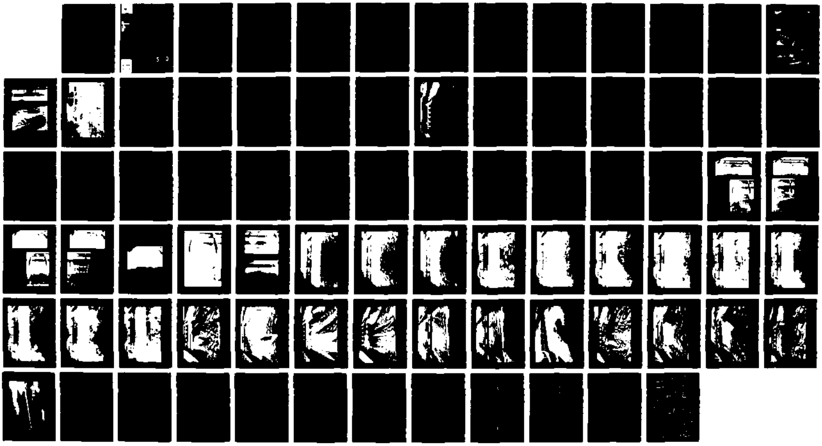

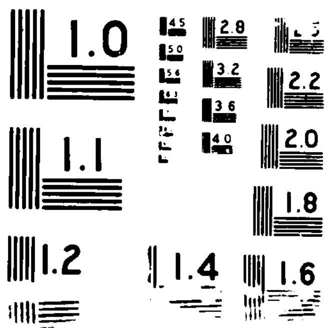
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US Army Corps of Engineers

TECHNICAL REPORT HL-88-5

OLD RIVER OVERBANK STRUCTURE, LOUISIANA

Hydraulic Model Investigation

by

John L. Grace, Jr., Noel R. Oswalt, Edward D. Rothwell

Hydraulics Laboratory

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Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Physical hydraulic model tests were conducted to investigate the hydraulic performance of the stilling basin and evaluate riprap stability and scour potential with the existing overbank structure. Most tests were conducted in a 1:25-scale section model of six bays and one abutment. Other tests were conducted in a 1:44-scale section model and the existing 1:120-scale general model. A variety of operating configurations with alternate bays and panels in each of the six bays were used to determine adequate operating conditions and limits of safe operation for the total 73-bay structure. Tests were conducted for the full range of anticipated operating conditions with consecutive bays fully open and fully closed, and with controlled flow through each of these timber panel configurations in each bay of the structure.

The stilling basin performance and existing downstream riprap protection were adequate for head differentials of 8.0 ft or less with alternate bays fully open and fully closed

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(staggered gate operations). However, severe scour occurred around the pier noses immediately upstream of the structure, and the upstream riprap protection was inadequate for headwaters equal to or greater than 66.5 ft (elevations referred to the National Geodetic Vertical Datum) with a head differential of 8.0 ft. A 30-in.-thick layer of riprap (weight of the largest stone size = 1,350 lb) was required to prevent severe scour upstream of the structure.

Controlled flow through a partially opened bay with staggered timber panels could be handled without modifying the existing overbank structure or riprap protection. Timber panels could be arranged to provide openings equivalent to 46.7, 53.5, and 66.7 percent of a fully opened bay for head differentials equal to or less than 13.0 ft (68.0-ft headwater elevation and 55.0-ft tailwater elevation).

Controlled flow through partially opened bays with staggered timber panels was the most satisfactory manner of operating the overbank structure and, therefore, is the recommended plan.

An approach dike of riprap was developed in the 1:120-scale general model for improving flow into the structure. This dike has been constructed in the prototype and performed very satisfactorily with the staggered timber panels during several flood flows in the early 1980's.

PREFACE

The model investigation reported herein was requested and authorized by the US Army Engineer District, New Orleans (NOD), on 23 May 1976.

The study was conducted during the period May 1976 to June 1977 in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) under the direction of Mr. H. B. Simmons, former Chief of the Hydraulics Laboratory, and under the general supervision of Messrs. J. L. Grace, Jr., former Chief of the Hydraulic Structures Division, and N. R. Oswalt, Chief of the Spillways and Channels Branch. Mr. G. A. Pickering is the present Chief of the Hydraulic Structures Division. The project engineer for the model study was Mr. E. D. Rothwell, assisted by Messrs. B. Perkins and E. Jefferson, all of the Spillways and Channels Branch. This report was prepared by Messrs. Grace, Oswalt, and Rothwell, and edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES.

During the course of the investigation, Messrs. S. Powell and J. Douma of the Office, Chief of Engineers, US Army; R. E. Louque, Jr., L. F. Cook, and H. E. Walker of the US Army Engineer Division, Lower Mississippi Valley/ Mississippi River Commission; and A. Becnel, Jr., I. Moss, Jr., J. Martin, G. Pilie, and T. Johnson of NOD visited WES to discuss the program and results of model tests, observe the model in operation, and correlate these results with design studies.

COL Dwayne G. Lee, CE, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms

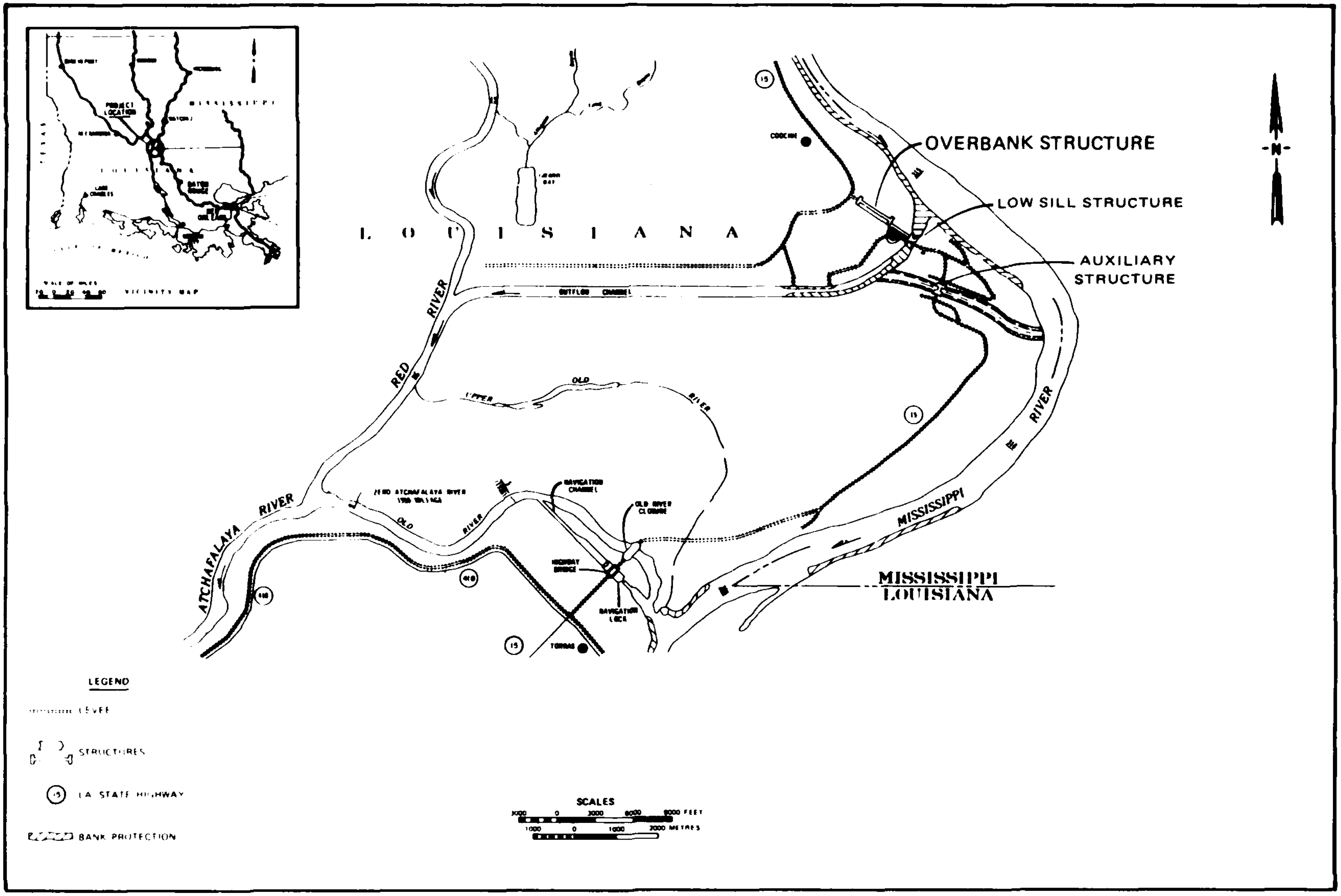

Figure 1. Site plan and vicinity map

OLD RIVER OVERBANK STRUCTURE, LOUISIANA

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Old River Overbank Structure is located on the west bank of the Mississippi River approximately 50 miles* northwest of Baton Rouge, Louisiana, and approximately 35 miles southwest of Natchez, Mississippi (Figure 1). The overbank structure consists of a reinforced concrete spillway with individual timber panels across each of the bays and stilling basin, an inflow approach from the Mississippi River, and an outflow to the Atchafalaya River and Basin along the right bank of the low-sill control structure outflow channel.

2. The structure (Plates 1 and 2) has a spillway length of 3,358 ft between abutments and consists of seventy-three 44-ft-wide spillway bays separated by 2-ft-thick concrete piers (numbered 1-73 from right to left looking downstream). The crest of the modified broad-crested spillway is located at el 52.0** (Plate 1). Flow through each spillway bay can be controlled by 15 individual panels. Each panel is about 2 ft 10-1/2 in. wide, 9-1/2 in. thick, and 18 ft long. The panels are hinged to the superstructure at their upper ends by two pins, sealed against a step at the crest of the weir at their lower ends, and are raised and lowered by the cable of a traveling crane located on the superstructure. Details of these panels are shown in Plate 3. The panels are now opened prior to a flood rather than during flow because previous model tests† indicated that they float at certain positions and stages and a downward force would be required to close them during flood conditions.

3. The stilling basin (Plate 2) consists of a horizontal apron 65 ft long, divided into two sections, surmounted with two rows of staggered

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

† US Army Engineer Waterways Experiment Station. 1959 (Feb). "Old River Overbank Structure, Forces on Panel Gates; Hydraulic Model Investigation," Technical Report 2-491, Vicksburg, Miss.

5-ft-high baffle piers, and terminated with a 4-ft-high vertical end sill. The first section, located immediately downstream of the weir and within the confines of the spillway piers, has an apron el of 43.0. The downstream portion has an apron el of 42.5.

Purpose and Scope of Model Study

4. Two spillway section models with scales of 1:25 and 1:44 were used to investigate the hydraulic performance of the stilling basin and evaluate riprap stability and scour potential to be expected with the existing overbank structure under both the immediate and long-range operating conditions. The study was conducted to evaluate performance of the existing stilling basin with the various headwater and tailwater conditions with (a) all bays fully open, (b) alternate bays fully open and fully closed, and (c) controlled flow through various configurations of panels in each bay of the structure to evaluate the necessity for major structural and/or operational modifications. The stability of the existing riprap protection and scour potential were also investigated for the full range of anticipated operating conditions to assess the need for structural or operational modifications.

5. An existing 1:120-scale general model was used to develop an approach dike of riprap for improving flow into the structure.

PART II: THE MODELS

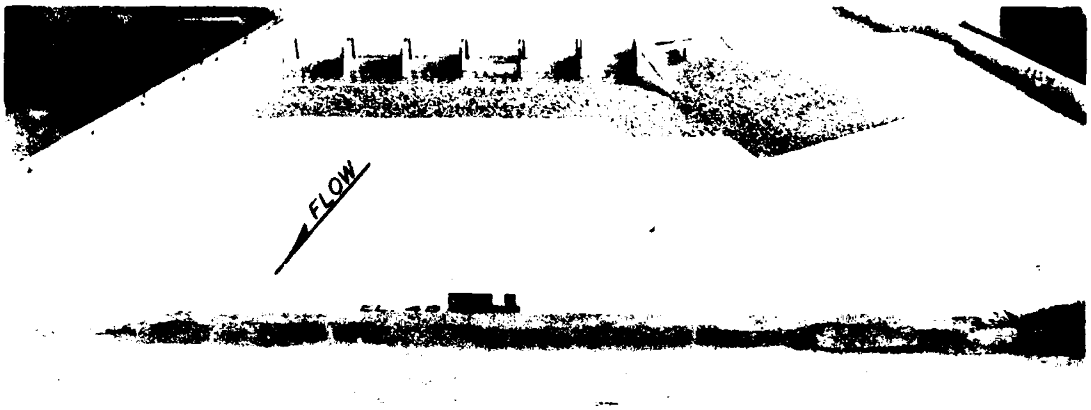
Description

6. The investigation was conducted using a 1:25-scale section model (Figure 2 and Plate 1), which reproduced a total width of about 526 ft including about 276 ft of the approach channel and about 250 ft of the adjacent abutment area, a portion of the spillway including six 44-ft-wide spillway bays and six 2-ft-wide piers, and the exit channel for a distance of about 385 ft. The portion of the model representing the approach and left abutment areas were molded of cement mortar to sheet metal templates, with the exception of the area immediately upstream of the structure. That area was molded with crushed and graded stone to simulate existing upstream riprap protection. The weir crest was fabricated of sheet metal. The stilling basin apron, crest piers, baffle piers, and end sill were fabricated of plastic-coated plywood and wood treated with a waterproofing compound to prevent expansion. The panels were fabricated of transparent plastic. The area immediately downstream of the end sill was molded with crushed and graded stone to simulate existing downstream riprap protection. For scour tests, selected portions of the model upstream and downstream of the existing riprap protection were molded in sand.

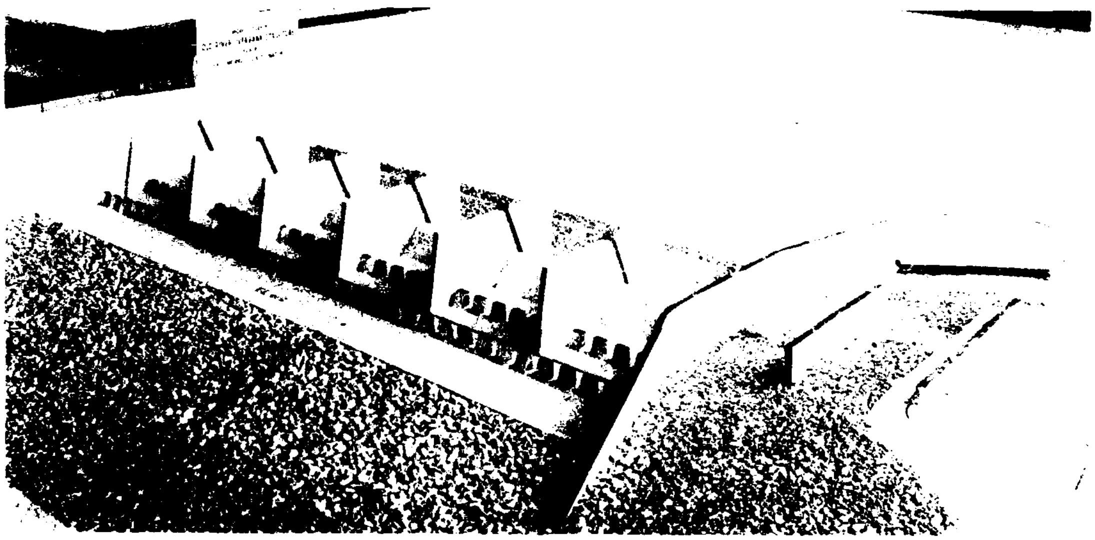
7. Initially, it was planned that all tests would be conducted using the 1:25-scale section model. However, it was found necessary to conduct a series of tests using a 1:44-scale section model simulating one 44-ft-wide spillway bay and 800 ft of the approach and exit channel in a 1-ft-wide glass-sided flume (Figure 3). These tests were conducted to identify and evaluate various types of flow conditions associated with a full range of expected operating conditions and to supplement various tests conducted in the 1:25-scale section model.

8. Supplementary to the tests conducted in the models described previously, tests were conducted in an existing 1:120-scale general fixed-bed model to investigate modifications to the approach to the overbank structure. This model (Figure 4) reproduced the entire low-sill and overbank structures with portions of the connecting levees and the approach and outflow channels.

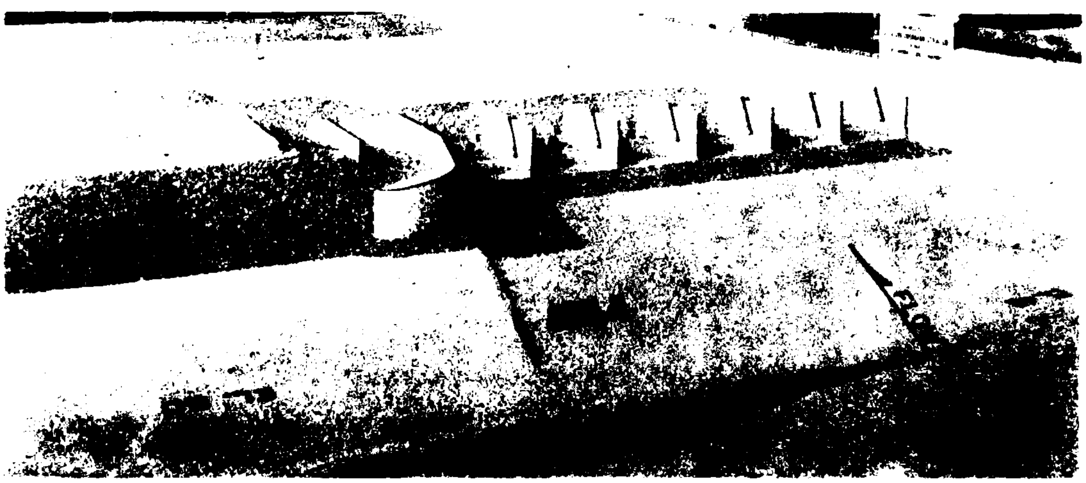
9. Water used in the operation of the models was supplied by pumps, and discharges were measured by means of venturi and orifice meters. Steel rails



a. Overall view of model width (526 ft)

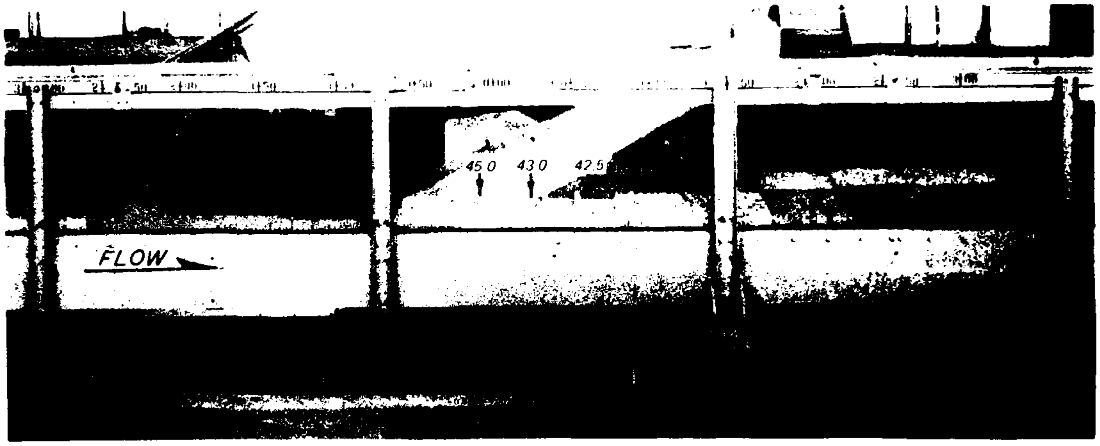


b. Closeup view of structure and left abutment

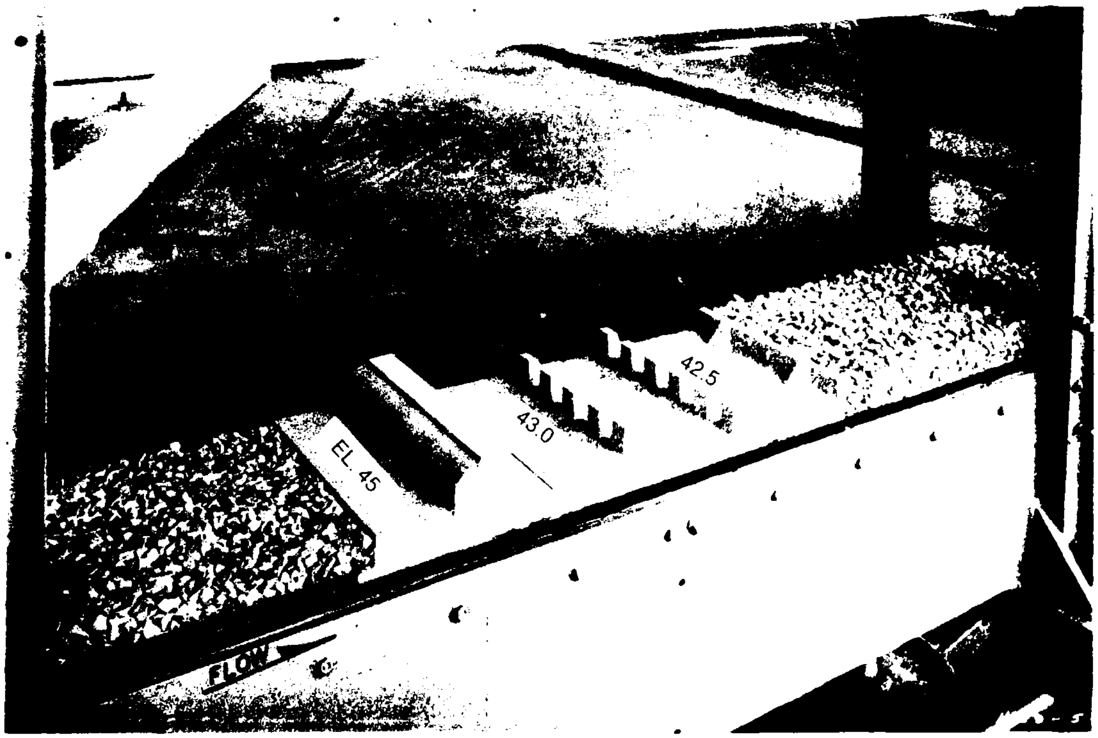


c. Upstream approach area

Figure 2. 1:25-scale dry-bed model



a. Overall view of one gate bay, upstream approach and downstream channel



b. Side view of one gate bay

Figure 3. 1:44-scale dry-bed section model

Figure 4. 1:120-scale fixed-bed model

set to grade provided reference planes for measuring devices. Water-surface elevations were obtained by point gages. Velocities were measured with pitot tubes and by stopwatch timing of movement of dye over a measured distance. Stilling basin action was determined by visual observation.

Scale Relations

10. The accepted equations of hydraulic similitude based upon the Froude criteria were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and prototype. The general relations expressed in terms of the model scale or length ratio L_r are presented in the following tabulation:

Dimension	Ratio	Scale Relations Model:Prototype		
Length	L_r	1:25	1:44	1:120
Area	$A_r = L_r^2$	1:625	1:1,936	1:14,400
Velocity	$V_r = L_r^{1/2}$	1:5	1:6.633	1:10.95
Discharge	$Q_r = L_r^{5/2}$	1:3,125	1:12,842	1:157,744
Time	$T_r = L_r^{1/2}$	1:5	1:6.633	1:10.95

11. Model measurements of each dimension or variable can be transferred quantitatively to prototype equivalents using the preceding scale relations. However, evidences of scour in the movable bed of sand used in the model are only qualitatively reliable, since the particle diameter of the sand was essentially the same size as that in the prototype. This similarity in size prevented simulation of the prototype ratio of depth of flow to diameter of bed material. The lack of exact simulation of the depth of flow to bed material size is common when fine-grained prototype bed materials are involved. Prototype scour depths will be larger than those indicated by such models, but no systematic research has been done as yet to determine appropriate scaling or adjusting relations. The qualitative results of scour tendencies in physical models are still of significant value in defining areas relatively free of scour and/or those subject to severe attack that need protection. Riprap stability tests using the 1:25-scale model are considered valid for the sizes involved in this case, and experience has shown that good correlations between

model and prototype can be expected when the ratio of depth of flow to particle diameter is preserved. This correlation normally requires that a Froudian model be large enough to preserve a sufficiently large Reynolds number of flow and the same fundamental character of flow as that of the prototype.

PART III: TESTS AND RESULTS

Stilling Basin Performance

12. Stilling basin performance of the existing overbank structure was investigated for the full range of operating conditions anticipated with uncontrolled flow through fully open spillway bays, with alternate bays fully open and fully closed, and with controlled flow through various configurations of the panels in each bay of the structure. Five types of stilling basin action might occur within the range of tailwater elevations expected:

a. Supercritical spray. Tailwater is less than that required for maintaining a hydraulic jump. The rapidly flowing nappe sweeps through the stilling basin and impinges upon and sprays over baffle piers and end sill. Supercritical flow exists throughout the stilling basin and a portion of the exit channel immediately downstream. Standing waves exist in the exit channel.

b. Forced jump with supercritical flow in the exit channel. Tailwater is less than that required for formation of a hydraulic jump but, with the combined resistance to flow due to the basin elements, is sufficient to maintain a hydraulic jump in the basin. Flow accelerates over the end sills due to the lack of sufficient tailwater, and supercritical flow occurs in the portion of the exit channel immediately downstream. Standing waves exist in the exit channel.

c. Hydraulic jump. The jet entering the stilling basin is broken up by the baffle piers, and tailwater is sufficient to maintain hydraulic jump action within the stilling basin and subcritical flow without standing waves in the downstream exit channel.

d. Submerged jump. Tailwater is in excess of that required for a free hydraulic jump, and the slope of the water surface and jump is mild. The nappe plunges into the stilling basin and flows along the apron and bottom of the exit channel.

e. Riding nappe. Tailwater is excessive, and the head differential ΔH across the structure is relatively small. The nappe therefore flows along and near the surface of the tailwater.

13. Test results obtained in the section models to determine the minimum tailwater required for maintaining a hydraulic jump in the stilling basin and to identify the types of stilling basin performance to be expected for the full range of operating conditions are tabulated in Table 1. Analyses of these data indicate satisfactory hydraulic flow conditions will occur in the existing stilling basin with headwater elevations equal to or less than 57.0 ft and tailwater elevations greater than 48.0 ft. The minimum tailwater

elevations required for maintaining hydraulic jump action in the stilling basin with headwater elevations greater than 57.0 ft are presented in Figure 5. The types of stilling basin action within the range of tailwater elevations at which the overbank structure may be required to operate are illustrated in Photos 1-5.

14. Stilling basin performance for a full range of operating conditions involving alternate bays fully open and fully closed (staggered gate operations) was observed in the model. The same types of stilling basin action were observed with alternate bays fully open and fully closed as with consecutive bays fully open. Supercritical spray, forced jump with supercritical flow in the exit channel, hydraulic jump, and submerged jump downstream of the gate bays are illustrated in Photos 6-9.

15. The existing 1:25-scale section model was modified to simulate the 15 individual timber panels as shown in Figure 6. Tests were then conducted to determine the hydraulic performance of the stilling basin with controlled flow through various configurations of the timber panels. The use of staggered timber panels is the most effective manner of operating the structure and maintaining satisfactory stilling basin performance. Stilling basin action observed with various timber panel configurations for a headwater el of 68.0 and a tailwater el of 60.0 are illustrated in Photos 10-18. Timber panel configurations used to obtain the four different percentages of opening in each bay are shown in Figure 7. A fifth percentage, 73.7, was tested; but hydraulic performance was not acceptable.

Stability of Riprap Protection

16. Tests were conducted in the 1:25-scale section model to investigate the stability of the existing riprap protection and scour potential upstream and downstream of the structure for a full range of anticipated operating conditions with consecutive bays fully open, alternate bays fully open and fully closed, and controlled flow through various timber panel configurations in each bay of the structure.

Consecutive bays fully open

17. Test results with all bays fully open are tabulated in Table 2. For each of the indicated operating conditions, the stability of the existing riprap protection was observed and average velocities were measured at a point

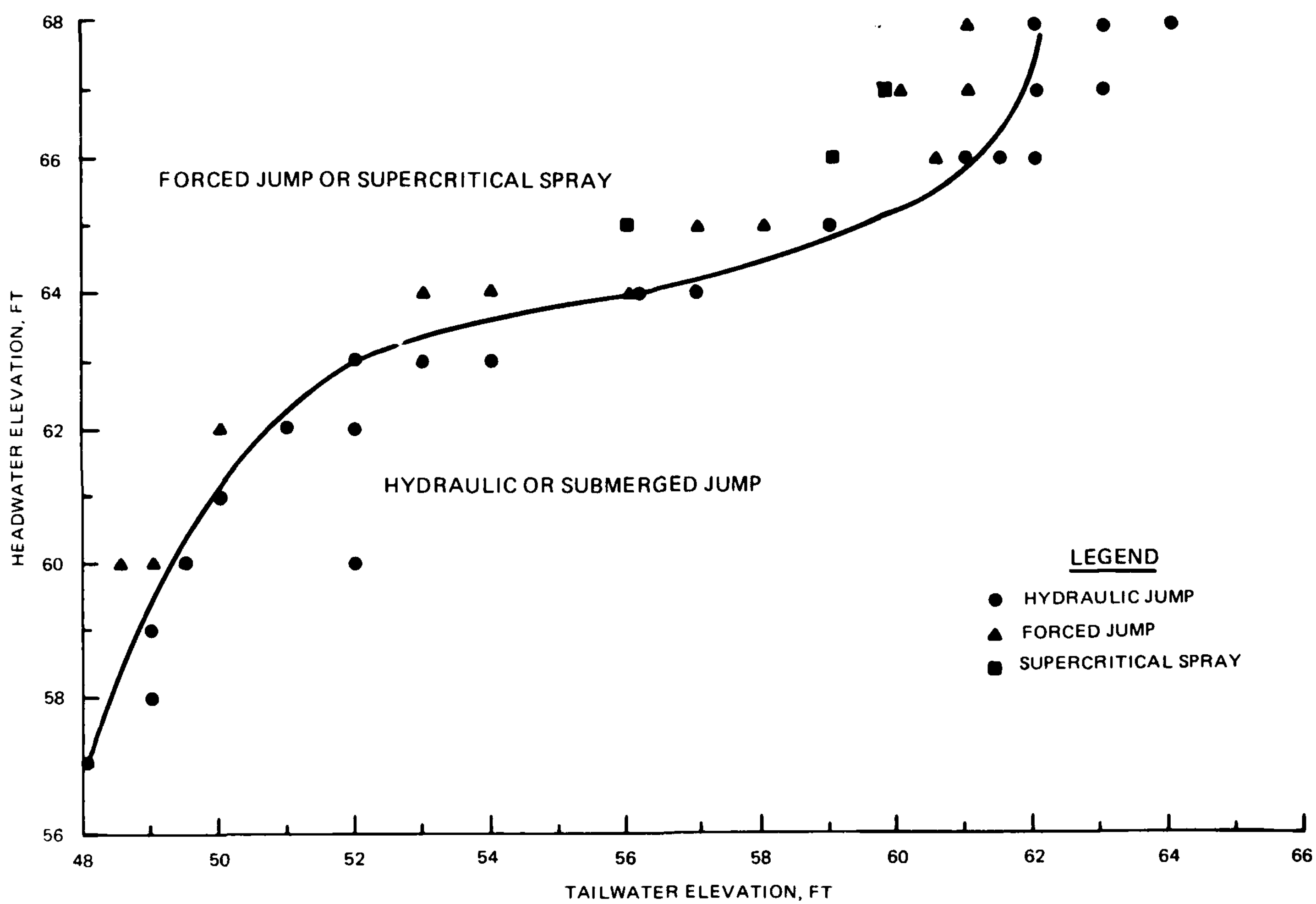


Figure 5. Stilling basin performance for uncontrolled flow

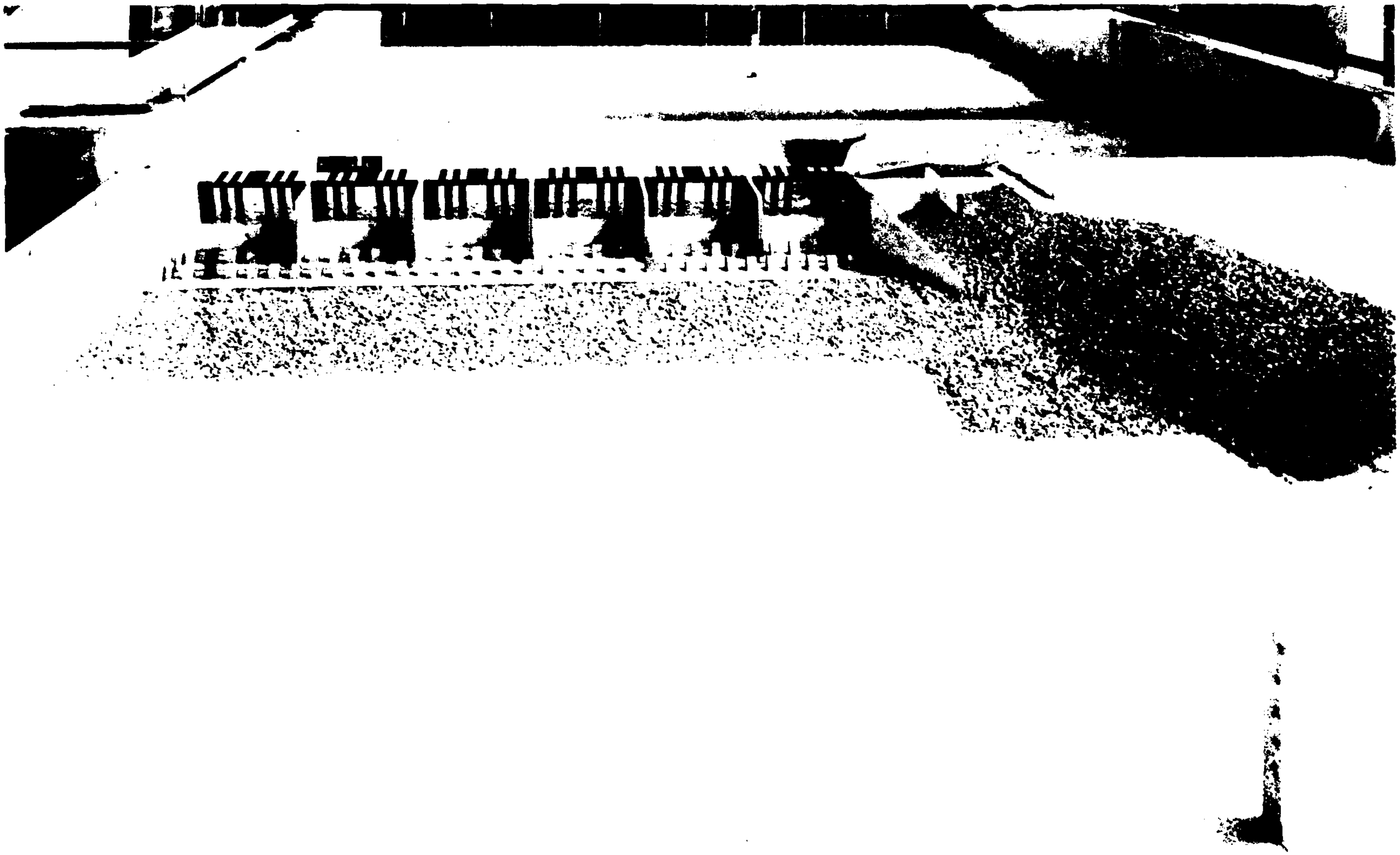


Figure 6. Gates with staggered timber panels

Configuration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Panel Numbers														
1	C	C	C	C	C	X	X	X	X	X	X	C	C	C	C
2	C	C	C	X	X	X	C	C	C	X	X	X	C	C	C
3	X	X	X	C	C	C	C	C	C	C	C	C	X	X	X

a. 40.0 percent opening/bay

Configuration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Panel Numbers														
1	C	C	X	C	X	C	X	X	X	C	X	C	X	C	C
2	C	C	X	X	C	C	X	X	X	C	C	X	X	C	C
3	X	C	C	C	X	X	C	C	C	X	X	C	C	X	X

b. 46.7 percent opening/bay

Configuration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Panel Numbers														
1	C	X	X	C	C	C	X	X	X	X	C	C	X	X	C
2	C	C	C	X	X	X	X	C	C	X	X	X	X	C	C
3	X	X	C	C	X	X	C	C	C	X	X	C	C	X	X

c. 53.3 percent opening/bay

Configuration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Panel Numbers														
1	X	C	X	X	C	X	X	C	X	X	C	X	X	C	X

d. 66.7 percent opening/bay

NOTE: Timber panels number from left to right looking downstream.

X = open timber panel.

C = closed timber panel.

Figure 7. Timber panel configurations

98 ft downstream of the end sill. Results of data analysis to distinguish the limits of existing riprap stability relative to the allowable head differential of 8.0 ft are presented in Plate 4. These results indicate that the existing riprap protection is stable with the design head differential of 8.0 ft for headwater elevations equal to or less than 64.5 ft, and unstable for headwater elevations greater than 64.5 ft. The areas of instability and scour potential observed with the existing riprap protection and various flow conditions are illustrated in Photos 19-22. Model results indicated that the existing upstream riprap protection was adequate with the design head differential of 8.0 ft.

Alternate bays fully
open and fully closed

18. Test results to determine the stability of the existing riprap protection and scour potential upstream and downstream of the structure with alternate bays fully open and closed (staggered gate operations) for a full range of anticipated operating conditions are tabulated in Table 3. For each of the indicated operating conditions, the stability of the existing riprap protection was observed and average velocities were measured at a point 98.0 ft downstream of the end sill.

19. Results of data analysis to distinguish the limits of upstream riprap stability relative to the allowable head differential are presented in Plate 5. The existing riprap protection is stable with the design head differential of 8.0 ft for headwater elevations equal to or less than 66.5 ft, and unstable for headwater elevations greater than 66.5 ft. The areas of instability and scour potential observed with the existing upstream riprap protection are illustrated in Photos 23 and 24. These results were analyzed and compared to those of previous tests conducted with five bays fully open (consecutive gate bays) and one bay closed as illustrated in Photo 25. The results indicate that the potential for scour immediately upstream of the structure is greater with staggered gate operations. The tendency for greater scour around the upstream pier noses indicates that the existing upstream riprap is inadequate for headwater elevations equal to or greater than 66.5 ft.

20. Results of data analysis to distinguish the limits of downstream riprap stability relative to the allowable head differential are presented in Plate 6. The results indicate that with staggered gate operations, the existing downstream riprap protection was adequate for the design head differential

of 8.0 ft. The areas of instability and scour potential observed downstream of the structure with head differential greater than 8.0 ft for various flow conditions are illustrated in Photos 26-28.

21. Additional tests were conducted with alternate bays fully open and fully closed for a limited and selected range of anticipated and future operation conditions furnished by the US Army Engineer District, New Orleans. Results of the tests are tabulated in Table 4.

Bays with staggered timber panels

22. The existing 1:25-scale section model was modified to simulate the 15 individual timber panels per bay (Figure 6) to evaluate the hydraulic performance and stability of the existing riprap protection and scour potential upstream and downstream of the structure with controlled flow through various configurations of the timber panels in each bay of the structure. Conditions that were investigated using several timber panel configurations are tabulated in Tables 5-7.

23. Initial results indicated that controlled flow through partially opened bays with selected timber panels is the most satisfactory manner of operating the structure. The design head differential of 8.0 ft (68.0-ft headwater elevation and 60.0-ft tailwater elevation) can be handled without modifying the existing stilling basin and riprap protection. Flow conditions and stilling basin action observed with various timber panel configurations for a headwater el of 68.0 and a tailwater el of 60.0 are illustrated in Photos 10-18.

24. Additional tests with controlled flow through partially opened bays were conducted for a limited and selected range of future operating conditions furnished by New Orleans District. Results of these tests are tabulated in Table 7. An analysis of these data indicated that a head differential of 13.0 ft (headwater el of 68.0 and tailwater el of 55.0) can be handled without modifying the existing stilling basin and riprap protection for selected timber panels arranged to provide openings equivalent to 46.7, 53.3, and 66.7 percent of a fully opened bay. Results of timber panels arranged to provide an opening equivalent to 73.7 percent indicated failure of the existing downstream riprap protection with a headwater el of 68.0 and a tailwater el of 55.0, as illustrated in Photo 29.

25. It is considered that controlled flow through partially opened bays with staggered timber panels would be the most effective method for operating

the structure to maintain satisfactory stilling basin performance and ensure the stability of the existing riprap protection. Therefore, it is the recommended plan for operating the structure.

Riprap Protection Modifications

26. Tests were conducted in the 1:25-scale section model to determine the gradation of riprap required to ensure adequate protection upstream of the existing structure in the vicinity of the pier noses with alternate bays fully open and fully closed (staggered bay operations). Results of these tests with uncontrolled flow conditions are tabulated in Table 8. Previous results obtained for staggered gate operations indicated that the original upstream riprap protection, Plan 1 (Plate 7), was stable with the design head differential of 8.0 ft for headwater elevations equal to or less than 66.5 ft and unstable for headwater elevations greater than 66.5 ft.

27. The model was modified to simulate the Plan 2 riprap protection (Plate 8) that consisted of a 24-in.-thick layer of riprap (weight of the largest stone size W_{100} = 691 lb). An analysis of the results indicated that the Plan 2 riprap protection is inadequate for staggered gate operations and headwater elevations equal to or greater than 67.0 ft (Table 8).

28. Plan 3 riprap protection (Plate 9) consisted of a 30-in.-thick layer of riprap (W_{100} = 1,350 lb). The test results indicated that the Plan 3 riprap protection was adequate with staggered gate operations and design head differential of 8.0 ft. The Plan 3 riprap protection is considered to prevent severe scour upstream of the structure for staggered gate operations.

Approach Dike

29. Modifications to the approach of the overbank structure were investigated in the 1:120-scale general fixed-bed model. A riverside modification was developed in conjunction with the wing wall replacement structure. The purpose of this structure was to improve flow conditions around the left abutment and in the adjacent bays of the overbank structure. In the development of the dike to the left of the overbank structure, current directions, velocities, and point velocities for the 1973 flood and project flood were used to evaluate the performance of the dike. The final recommended plan (Plate 10)

consists of a curved dike tied into the existing levee 120 ft to the left of the overbank abutment and shaped to provide a smooth transition for flow into the structure. This dike has been constructed in the prototype (Photo 30).

30. Several flood flows have passed through the overbank structure since 1978 (1979, 1982, 1983, 1984, and 1985) using the present partially opened bays with staggered panels to control the flow. An aerial photograph taken during the 1983 flow event (Photo 30) shows the stucture with an opening equivalent to 53.3 percent. Favorable conditions were obtained in the stilling basin and the immediate exit area during all five flow events. No repairs have been required to the overbank structure or the immediate approach or exit areas due to scour or instability of stone during January 1977 to January 1988.

PART IV: DISCUSSION AND RECOMMENDATIONS

31. Section model (1:25 scale of six bays) investigations were conducted to assess stilling basin performance, riprap stability, and scour potential to be expected with the existing overbank structure and the need for any required modifications. Tests were conducted for the full range of anticipated operating conditions with consecutive bays fully open, with alternate bays fully open and fully closed, and with controlled flow through each of three configurations of the timber panels in each bay of the structure.

32. Tests to identify the types of stilling basin action that may occur and the minimum allowable tailwater required to maintain a hydraulic jump in the stilling basin with consecutive bays fully open indicate that the existing stilling basin will provide satisfactory performance for headwater elevations equal to or less than 57.0 ft and tailwater elevations greater than 48.0 ft. These tests were conducted in both the 1:44- and the 1:25-scale models. The minimum allowable tailwater elevations for headwater elevations greater than 57.0 ft were determined. The existing riprap protection was stable with head differentials as large as 8.0 ft and headwater elevations equal to or less than 65.0 ft. It was unstable with greater headwaters. The potential for local scour immediately downstream of the riprap protection was indicated by the model; however, this should not endanger the structural adequacy of the overbank structure.

33. The stilling basin performance and existing downstream riprap protection were adequate for head differentials of 8.0 ft or less with alternate bays fully open and fully closed (staggered gate operations). However, severe scour occurred around the pier noses immediately upstream of the structure and the upstream riprap protection was inadequate for headwater elevations equal to or greater than 66.5 ft with a head differential of 8.0 ft. A 30-in.-thick layer of riprap (W_{100} = 1,350 lb) would be required to prevent severe scour upstream of the structure.

34. Controlled flow through partially opened bays with staggered timber panels can be handled without modifying the existing overbank structure and riprap protection. Timber panels can be arranged to provide openings equivalent to 46.7, 53.3, and 66.7 percent of a fully opened bay for head differential equal to or less than 13.0 ft (headwater el 68.0 and tailwater el 55.0).

35. Controlled flow through partially opened bays with staggered timber

Table 1

Stilling Basin Performance for Consecutive Bays Fully Open

Operating Conditions			
Headwater El	Tailwater El	ΔH	Stilling Basin Peformance
54.0	48.0	6.0	Free plunging nappe
54.0	50.0	4.0	Free plunging nappe
54.0	52.0	2.0	Free plunging nappe
56.0	48.0	8.0	Hydraulic jump, plunging nappe
56.0	50.0	6.0	Hydraulic jump, plunging nappe
56.0	52.0	4.0	Hydraulic jump, plunging nappe
56.0	54.0	2.0	Submerged jump, plunging nappe
57.0	48.0	9.0	Hydraulic jump
58.0	48.5	9.5	Hydraulic jump
58.0	49.0	9.0	Hydraulic jump
58.0	50.0	8.0	Hydraulic jump
58.0	52.0	6.0	Hydraulic jump
58.0	54.0	4.0	Submerged jump
58.0	56.0	2.0	Submerged jump
59.0	49.0	10.0	Hydraulic jump
60.0	48.0	12.0	Forced jump
60.0	48.5	11.5	Forced jump
60.0	49.0	11.0	Forced jump
60.0	49.5	10.5	Hydraulic jump
60.0	50.0	10.0	Hydraulic jump
60.0	52.0	8.0	Hydraulic jump
60.0	54.0	6.0	Submerged jump
60.0	56.0	4.0	Submerged jump
60.0	58.0	2.0	Submerged jump
61.0	50.0	11.0	Hydraulic jump
62.0	50.0	12.0	Forced jump
62.0	51.0	11.0	Forced jump
62.0	52.0	10.0	Hydraulic jump
62.0	53.0	9.0	Hydraulic jump
62.0	54.0	8.0	Hydraulic jump
62.0	56.0	6.0	Hydraulic jump
62.0	58.0	4.0	Hydraulic jump
62.0	60.0	2.0	Submerged jump
63.0	52.0	11.0	Forced jump
63.0	53.0	10.0	Hydraulic jump
63.0	54.0	9.0	Hydraulic jump

(Continued)

panels is the most satisfactory manner of operating the overbank structure and, therefore, is the recommended plan.

36. The recommended approach dike plan consists of a curved dike connected to the existing levee 120 ft to the left of the overbank abutment and shaped to provide a smooth transition for flow into the structure. This plan, which was developed in the 1:120-scale existing model, has been constructed in the prototype.

Table 1 (Concluded)

Operating Conditions			
Headwater El	Tailwater El	ΔH	Stilling Basin Peformance
64.0	53.0	11.0	Forced jump
64.0	54.0	10.0	Forced jump
64.0	56.0	8.0	Hydraulic jump
64.0	57.0	7.0	Hydraulic jump
64.0	58.0	6.0	Hydraulic jump
64.0	60.0	4.0	Hydraulic jump
64.0	62.0	2.0	Submerged jump
65.0	54.0	11.0	Supercritical spray
65.0	55.0	10.0	Supercritical spray
65.0	56.0	9.0	Supercritical spray
65.0	57.0	8.0	Forced jump
65.0	58.0	7.0	Forced jump
65.0	59.0	6.0	Hydraulic jump
66.0	56.0	10.0	Supercritical spray
66.0	58.0	8.0	Supercritical spray
66.0	59.0	7.0	Forced jump
66.0	60.0	6.0	Forced jump
66.0	61.0	5.0	Hydraulic jump
66.0	62.0	4.0	Hydraulic jump
67.0	59.5	7.5	Supercritical spray
67.0	60.0	7.0	Forced jump
67.0	61.0	6.0	Forced jump
67.0	62.0	5.0	Hydraulic jump
67.0	63.0	4.0	Hydraulic jump
68.0	60.0	8.0	Forced jump
68.0	61.0	7.0	Forced jump
68.0	62.0	6.0	Hydraulic jump
68.0	63.0	5.0	Hydraulic jump
68.0	64.0	4.0	Hydraulic jump

Table 2

Stability of Existing Riprap Protection for Consecutive Bays Fully Open

Operating Conditions			Stability of Existing Riprap		Average Velocity 98 ft Downstream of End Sill, fps
Headwater El	Tailwater El	ΔH	Upstream	Downstream	
58.0	50.0	8.0	Stable	Stable	9.8
58.0	49.0	9.0	Stable	Stable	10.6
58.0	48.5	9.5	Stable	Failure	15.6
58.0	48.0	10.0	Stable	Failure	15.0
60.0	51.0	9.0	Stable	Stable	13.0
60.0	50.0	10.0	Stable	Stable	13.3
60.0	49.0	11.0	Stable	Failure	17.0
60.0	48.0	12.0	Stable	Failure	18.0
62.0	54.0	8.0	Stable	Stable	8.4
62.0	53.0	9.0	Stable	Stable	14.5
62.0	52.0	10.0	Stable	Failure	21.6
62.0	51.0	11.0	Stable	Failure	17.5
63.0	55.0	8.0	Stable	Stable	14.0
63.0	54.0	9.0	Stable	Stable	18.0
63.0	53.0	10.0	Stable	Failure	21.2
63.0	52.0	11.0	Stable	Failure	26.0
64.0	57.0	8.0	Stable	Stable	17.5
64.0	56.0	9.0	Stable	Stable	18.8
64.0	54.5	9.5	Stable	Stable	17.0
64.0	54.0	10.0	Stable	Failure	17.0
64.0	53.0	11.0	Stable	Failure	22.0
65.0	59.0	6.0	Stable	Stable	12.1
65.0	58.0	7.0	Stable	Stable	17.5
65.0	57.0	8.0	Stable	Stable	19.7
65.0	56.0	9.0	Stable	Failure	22.4
65.0	55.0	10.0	Stable	Failure	23.7
66.0	62.0	4.0	Stable	Stable	12.1
66.0	61.0	5.0	Stable	Stable	12.7
66.0	60.0	6.0	Stable	Stable	19.7
66.0	59.0	7.0	Stable	Failure	17.5
67.0	63.0	4.0	Stable	Stable	12.1
67.0	62.0	5.0	Stable	Stable	13.9
67.0	61.0	6.0	Stable	Stable	15.6
67.0	60.0	7.0	Stable	Stable	18.4
67.0	59.5	7.5	Stable	Failure	22.0

(Continued)

Table 2 (Concluded)

Operating Conditions					
Headwater El	Tailwater El	ΔH	Stability of Existing Riprap: Upstream	Stability of Existing Riprap: Downstream	Average Velocity 98 ft Downstream of End Sill, fps
68.0	64.0	4.0	Stable	Stable	13.3
68.0	63.0	5.0	Stable	Stable	13.9
68.0	62.0	6.0	Stable	Stable	14.5
68.0	61.0	7.0	Stable	Failure	17.0
68.0	60.0	8.0	Stable	Failure	19.3

Table 3

Stability of Existing Riprap Protection for Alternate Bays Fully Open and Fully Closed

Operating Conditions					
Head-water El	Tail-water El	ΔH	Stability of Existing Riprap Upstream	Stability of Existing Riprap Downstream	Average Velocity 98 ft Downstream of End Sill, fps
55.0	48.0	7.0	Stable	Stable	2.8
56.0	54.0	2.0	Stable	Stable	2.8
56.0	52.0	4.0	Stable	Stable	2.8
56.0	50.0	6.0	Stable	Stable	3.7
56.0	48.0	8.0	Stable	Stable	4.0
57.0	54.0	3.0	Stable	Stable	2.8
57.0	52.0	5.0	Stable	Stable	3.7
57.0	50.0	7.0	Stable	Stable	5.7
57.0	48.0	9.0	Stable	Stable	6.0
58.0	52.0	6.0	Stable	Stable	4.0
58.0	50.0	8.0	Stable	Stable	6.4
58.0	49.0	9.0	Stable	Stable	6.9
58.0	48.0	10.0	Stable	Stable	8.9
59.0	53.0	6.0	Stable	Stable	6.9
59.0	52.0	8.0	Stable	Stable	6.9
59.0	50.0	9.0	Stable	Stable	8.9
59.0	49.0	10.0	Stable	Stable	11.4
59.0	48.0	11.0	Stable	Stable	13.3
60.0	54.0	6.0	Stable	Stable	6.9
60.0	52.0	8.0	Stable	Stable	6.9
60.0	50.0	10.0	Stable	Stable	13.3
60.0	49.0	11.0	Stable	Stable	15.0
61.0	54.0	7.0	Stable	Stable	8.0
61.0	52.0	9.0	Stable	Stable	10.6
61.0	50.0	11.0	Stable	Stable	15.0
61.0	49.0	12.0	Stable	Stable	17.0
62.0	54.0	8.0	Stable	Stable	9.8
62.0	53.0	9.0	Stable	Stable	11.4
62.0	52.0	10.0	Stable	Stable	13.3
62.0	51.0	11.0	Stable	Stable	13.3
63.0	56.0	7.0	Stable	Stable	8.9
63.0	54.0	9.0	Stable	Stable	12.1
63.0	52.0	11.0	Stable	Stable	17.0
63.0	50.0	13.0	Stable	Failure	21.1

(Continued)

Table 3 (Concluded)

Operating Conditions					
Head-water El	Tail-water El	ΔH	Stability of Existing Riprap Upstream	Downstream	Average Velocity 98 ft Downstream of End Sill, fps
64.0	57.0	7.0	Stable	Stable	8.0
64.0	56.0	8.0	Stable	Stable	12.1
64.0	54.0	10.0	Stable	Stable	13.9
64.0	54.0	12.0	Failure	Failure	18.8
65.0	58.0	7.0	Stable	Stable	10.6
65.0	57.0	8.0	Stable	Stable	12.7
65.0	56.0	9.0	Stable	Stable	13.9
65.0	54.0	11.0	Failure	Failure	16.1
66.0	59.0	7.0	Stable	Stable	11.4
66.0	58.0	8.0	Stable	Stable	12.7
66.0	56.0	10.0	Failure	Stable	15.0
66.0	54.0	12.0	Failure	Failure	17.9
66.0	52.0	14.0	Failure	Failure	23.1
67.0	60.0	7.0	Stable	Stable	12.1
67.0	59.0	8.0	Failure	Stable	13.9
67.0	58.0	9.0	Failure	Stable	15.0
67.0	56.0	11.0	Failure	Failure	15.6
67.0	55.0	12.0	Failure	Failure	16.1
68.0	61.0	7.0	Failure	Stable	9.8
68.0	60.0	8.0	Failure	Stable	12.1
68.0	58.0	10.0	Failure	Failure	13.3
68.0	56.0	12.0	Failure	Failure	17.0

Table 4

Riprap Stability and Stilling Basin Performance

Alternate Bay Operations With Gates Fully

Open and Fully Closed

Headwater El	Tailwater El	Stability of Riprap Upstream	Stability of Riprap Downstream	Stilling Basin Performance
		Existing Overbank Structure Without Modifications		
55.9	48.0	Stable	Stable	Satisfactory
57.5	49.5	Stable	Stable	Satisfactory
59.1	50.9	Stable	Stable	Unsatisfactory*
60.7	52.5	Stable	Stable	Unsatisfactory*
62.3	53.5	Stable	Stable	Unsatisfactory*
63.9	54.7	Stable	Failure	Unsatisfactory*
65.6	55.8	Failure	Failure	Unsatisfactory**
		Existing Overbank Structure with Increased Tailwater Downstream		
55.5	49.6	Stable	Stable	Satisfactory
57.0	51.6	Stable	Stable	Satisfactory
58.5	53.4	Stable	Stable	Satisfactory
59.9	55.4	Stable	Stable	Satisfactory
61.4	57.2	Stable	Stable	Satisfactory

* Forced jump with jet riding over end sill and plunging into riprap.

** Spray action with jet sweeping through the stilling basin.

Table 5

Stability of Existing Riprap Protection

Opening percent per Bay	Discharge cfs per Bay	Head-water El	Tail-water El	Timber Panel Configuration	Stability of Riprap Upstream	Stability of Riprap Downstream
40.0	3,580	68.0	60.0	1	Stable	Stable
				2	Stable	Stable
				3	Stable	Stable
46.7	4,580	68.0	60.0	1	Stable	Stable
				2	Stable	Stable
				3	Stable	Stable
53.3	5,330	68.0	60.0	1	Stable	Stable
				2	Stable	Stable
				3	Stable	Stable
40.0	2,580	64.0	56.0	1	Stable	Stable
				2	Stable	Stable
				3	Stable	Stable
46.7	3,330	64.0	56.0	1	Stable	Stable
				2	Stable	Stable
				3	Stable	Stable
53.3	3,750	64.0	56.0	1	Stable	Stable
				2	Stable	Stable
				3	Stable	Stable

Table 6

Stability of Existing Riprap Protection

46.7 Percent Opening per Bay, Configuration 1

Discharge per Bay, cfs	Headwater El	Tailwater El	Stability of Riprap	
			Upstream	Downstream
1,670	60.0	52.0	Stable	Stable
1,670	60.0	51.0	Stable	Stable
2,250	61.0	53.0	Stable	Stable
2,250	61.0	52.0	Stable	Stable
2,580	62.0	54.0	Stable	Stable
2,580	62.0	53.0	Stable	Stable
3,000	63.0	55.0	Stable	Stable
3,000	63.0	54.0	Stable	Stable
3,330	64.0	56.0	Stable	Stable
3,330	64.0	55.0	Stable	Stable
3,750	65.0	57.0	Stable	Stable
3,750	65.0	56.0	Stable	Stable
4,083	66.0	58.0	Stable	Stable
4,083	66.0	57.0	Stable	Stable
4,330	67.0	59.0	Stable	Stable
4,330	67.0	58.0	Stable	Stable
4,580	68.0	60.0	Stable	Stable
4,580	68.0	59.0	Stable	Stable

Table 7

Stability of Existing Riprap Protection

46.7 and 66.7 Percent Openings per Bay with Timber Panels

Headwater El	Tailwater El	Stability of Riprap Upstream	Stability of Riprap Downstream	Stilling Basin Performance
		46.7 Percent Opening per Bay*		
68.0	59.0	Stable	Stable	Satisfactory
68.0	58.0	Stable	Stable	Satisfactory
68.0	57.0	Stable	Stable	Satisfactory
68.0	56.0	Stable	Stable	Satisfactory
68.0	55.0	Stable	Stable	Satisfactory
68.0	54.0	Stable	Stable	Hydraulic jump**
68.0	53.0	Stable	Failure	Forced jump
68.0	52.0	Stable	Failure	Forced jump
		66.7 Percent Opening per Bay†		
54.4	48.0	Stable	Stable	Satisfactory
56.0	49.5	Stable	Stable	Satisfactory
57.6	50.9	Stable	Stable	Satisfactory
59.4	52.2	Stable	Stable	Satisfactory
60.9	53.5	Stable	Stable	Satisfactory
62.5	54.7	Stable	Stable	Satisfactory
64.1	55.8	Stable	Stable	Satisfactory
65.0	56.5	Stable	Stable	Satisfactory
68.0	55.0	Stable	Stable	Satisfactory

* Configuration consisted of 15 staggered timber panels: 7 open and 8 closed.

** Hydraulic jump with formation of a standing wave in the exit channel.

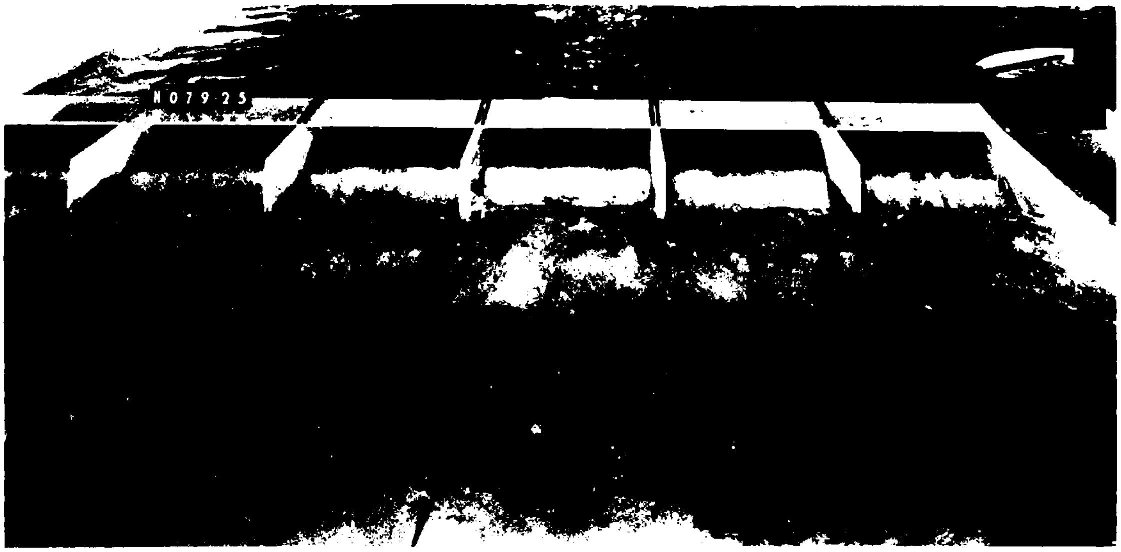
† Configuration consisted of 15 staggered timber panels: 10 open and 5 closed.

Table 8

Stability of Upstream Riprap Protection with Uncontrolled Flow and Staggered Gate Operations

Headwater El	Tailwater El	Condition of Riprap		
		Plan 1	Plan 2	Plan 3
62.0	54.0	Stable	Stable	Stable
63.0	55.0	Stable	Stable	Stable
64.0	56.0	Stable	Stable	Stable
65.0	57.0	Stable	Stable	Stable
66.0	58.0	Stable	Stable	Stable
67.0	59.0	Failed	Failed	Stable
68.0	60.0	Failed	Failed	Stable

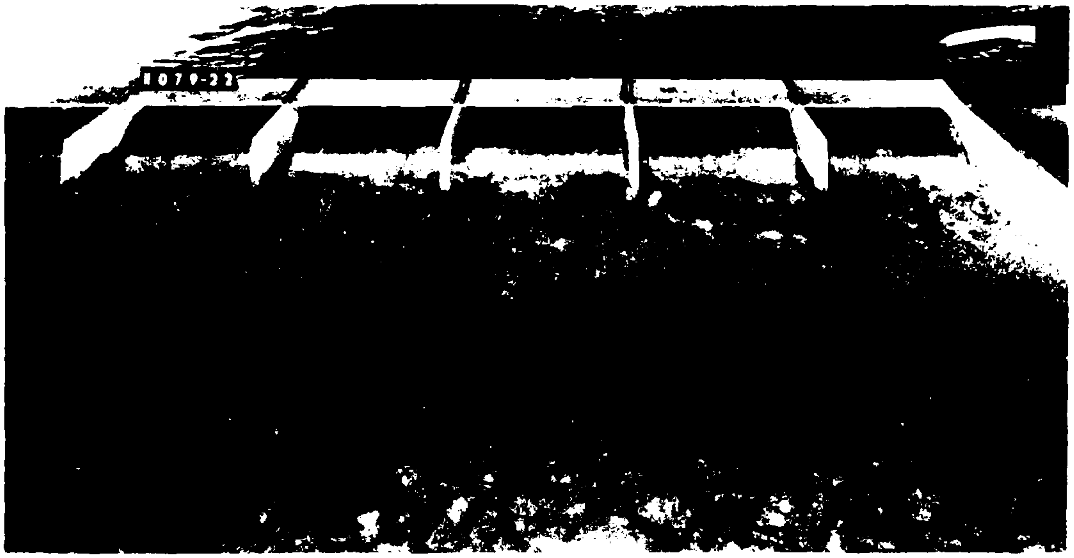
Note: Plan 1 consists of an 18-in.-thick layer of riprap (W_{100} = 292 lb).
Plan 2 consists of a 24-in.-thick layer of riprap (W_{100} = 691 lb).
Plan 3 consists of a 30-in.-thick layer of riprap (W_{100} = 1,350 lb).



a. Headwater el 65.0, tailwater el 56.0

b. Headwater el 66.0, tailwater el 56.0

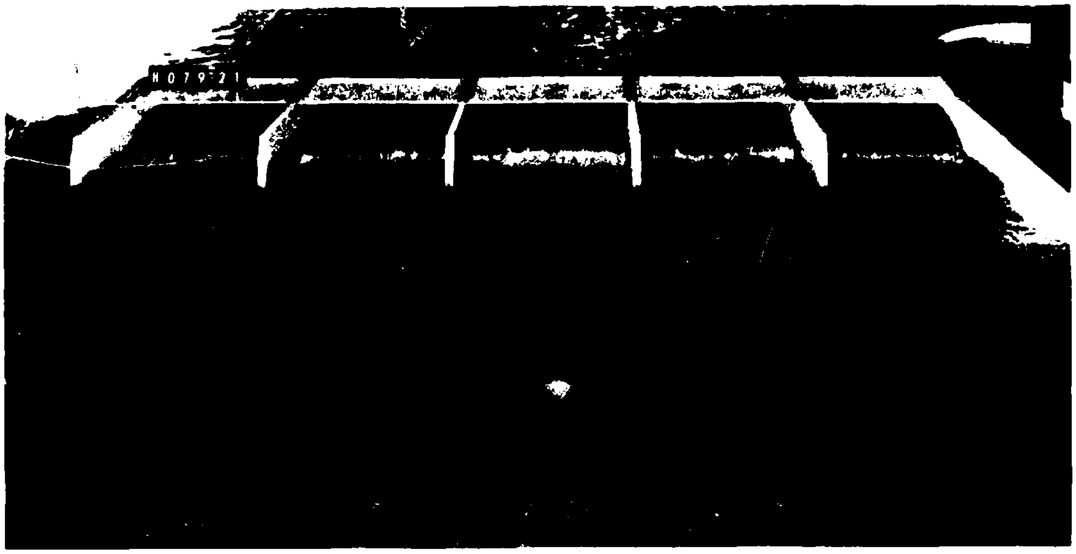
Photo 1. Supercritical spray



a. Headwater el 64.0, tailwater el 53.0

b. Headwater el 64.0, tailwater el 53.0, closeup view

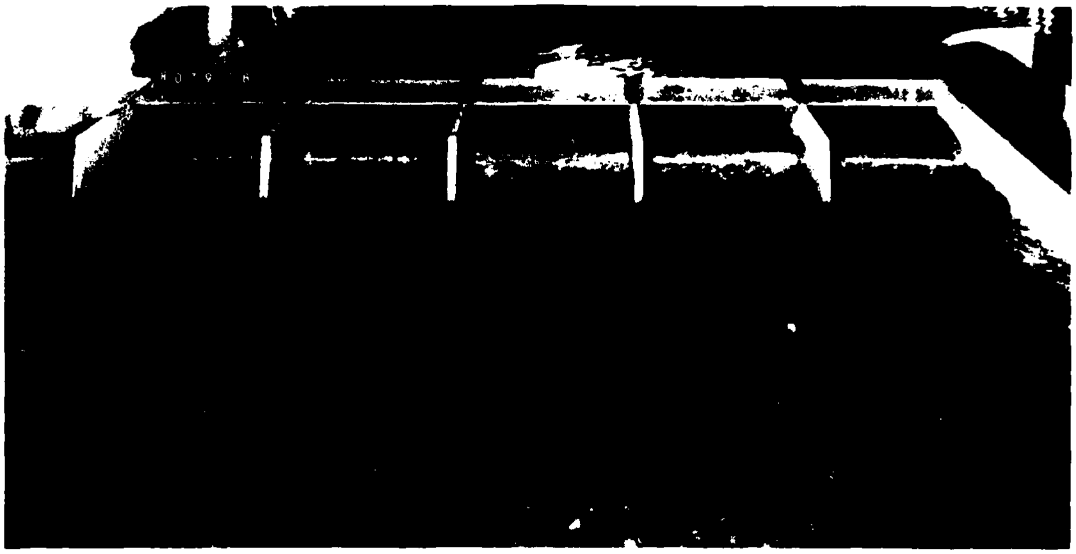
Photo 2. Forced jump with supercritical flow in the exit channel



a. Headwater el 62.0, tailwater el 54.0

b. Headwater el 62.0, tail-
water el 54.0, closeup
view

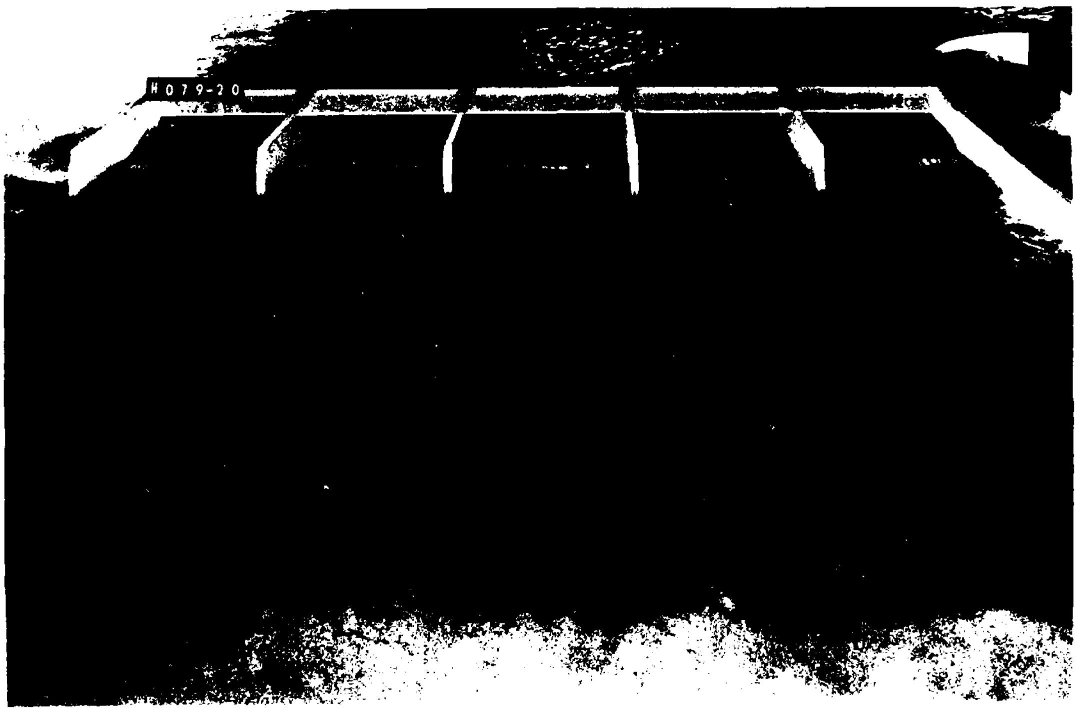
Photo 3. Hydraulic jump



a. Headwater el 58.0, tailwater el 54.0

b. Headwater el 56.0, tailwater el 48.0

Photo 4. Submerged jump (Continued)



c. Headwater el 60.0, tailwater el 58.0

Photo 4. (Concluded)

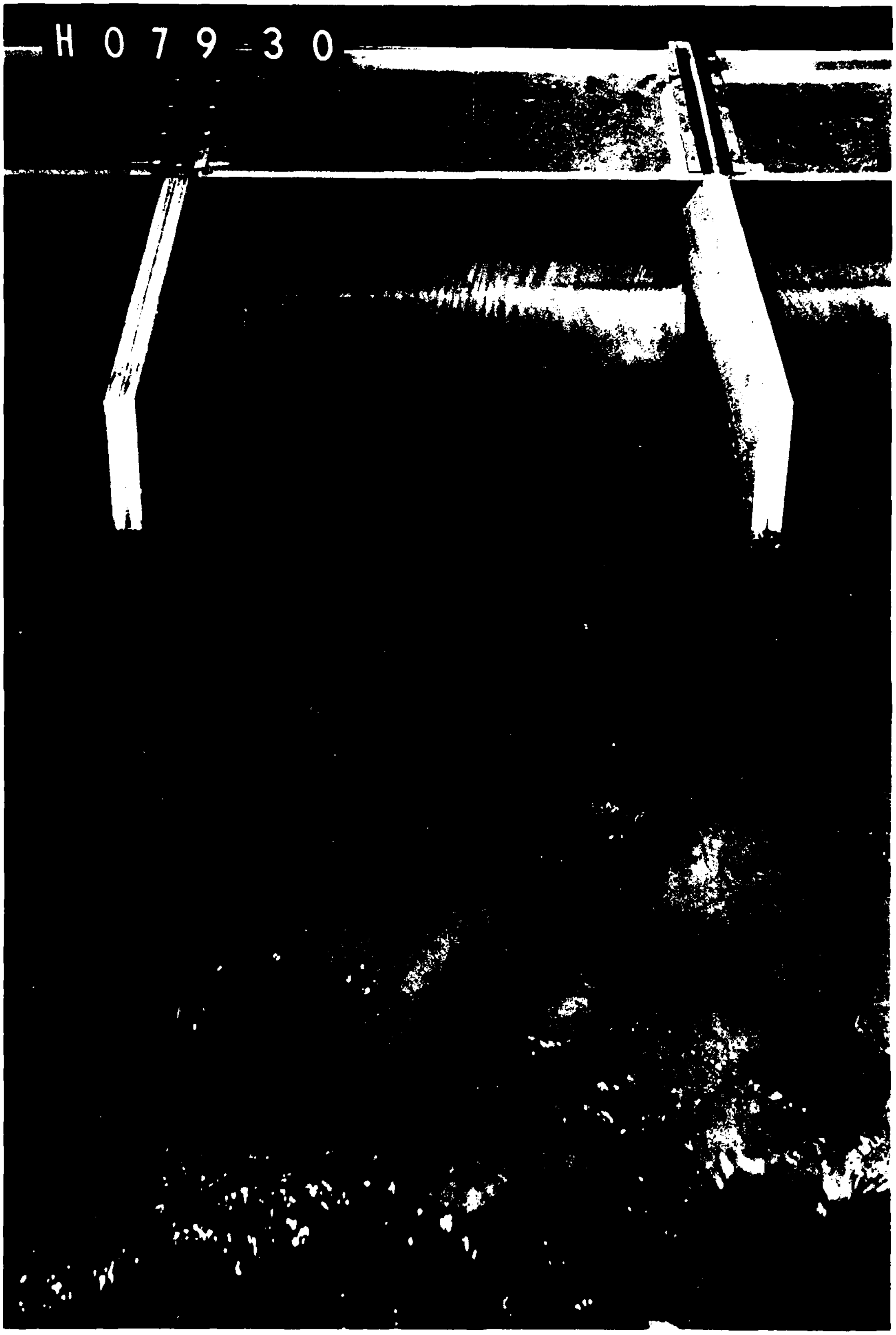
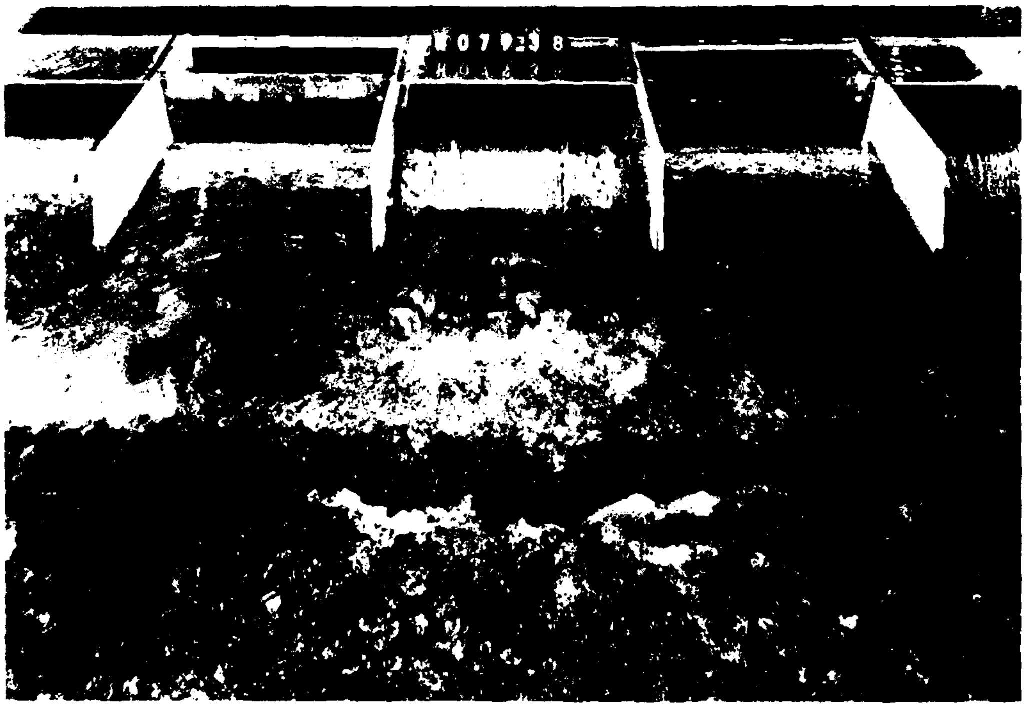
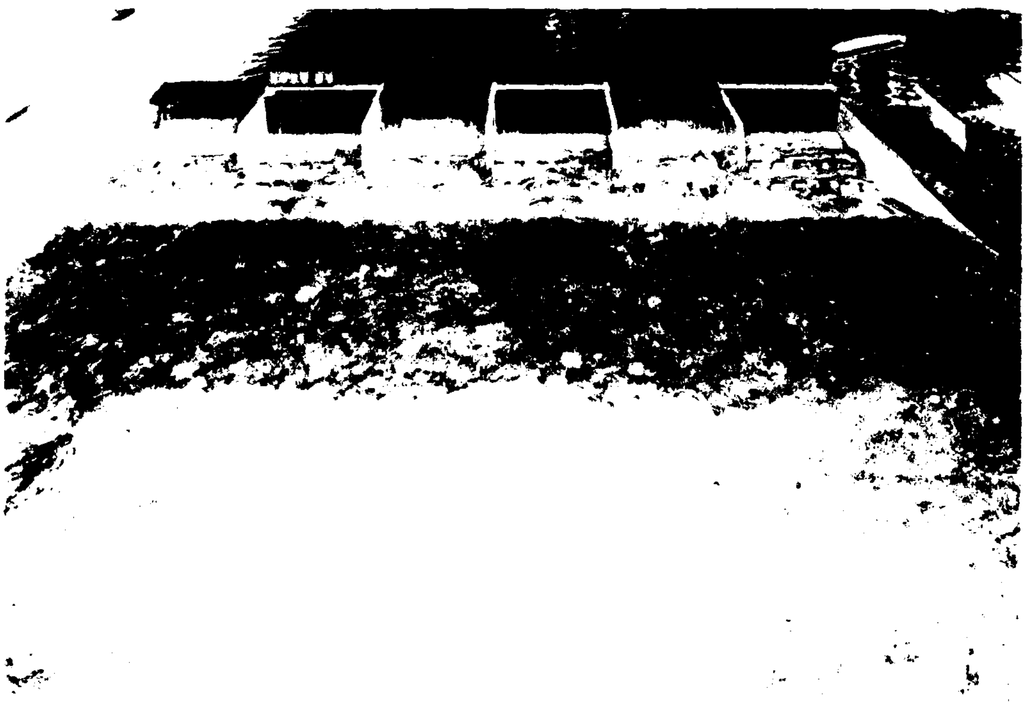


Photo 5. Riding surface nappe, headwater el 60.0, tailwater el 58.0



a. Headwater el 63.0, tailwater el 50.0



b. Headwater el 65.0, tailwater el 54.0

Photo 6. Supercritical spray, alternate bays fully open and fully closed

Photo 7. Forced jump with supercritical flow in the exit channel, alternate bays fully open and fully closed

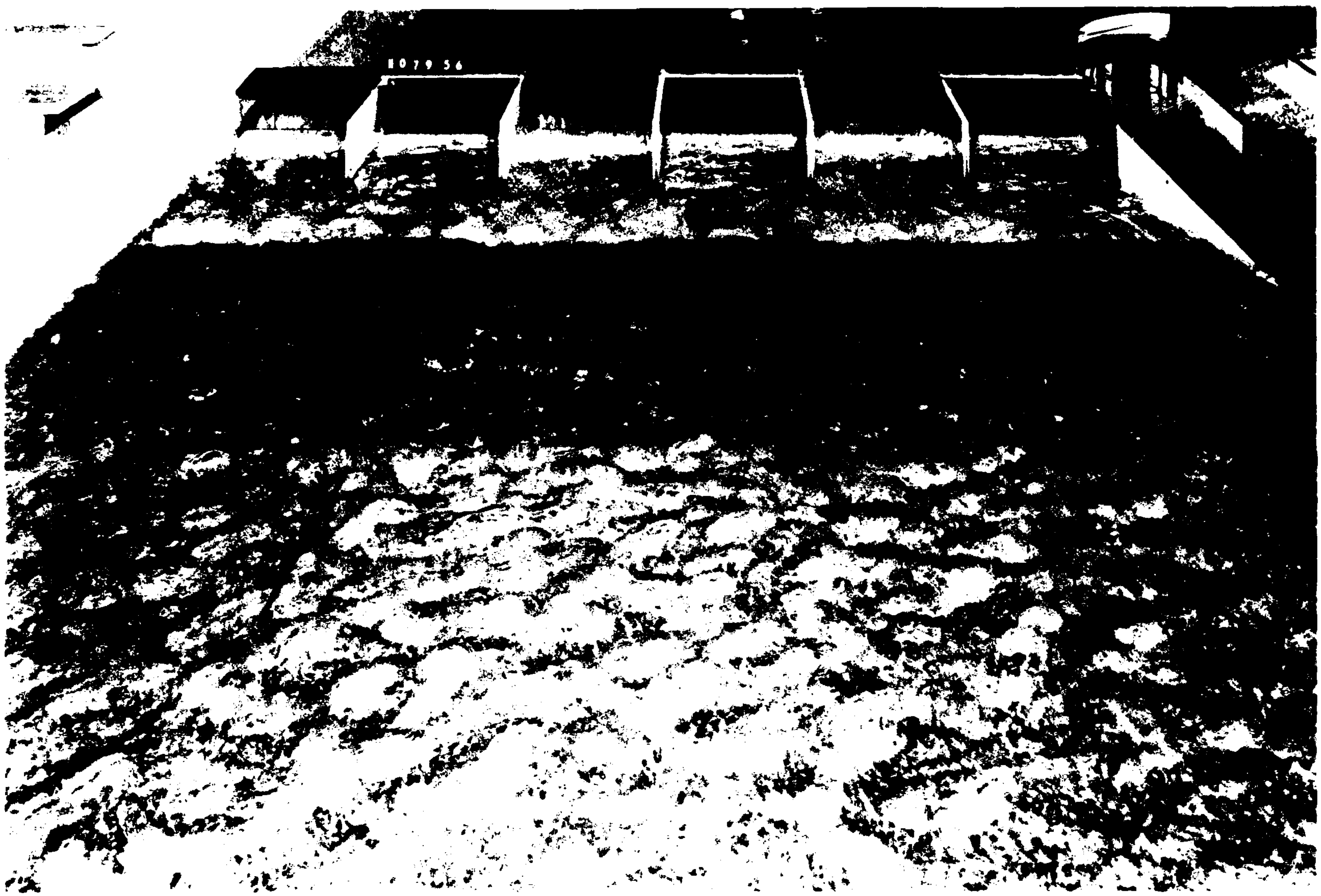


Photo 8. Hydraulic jump, alternate bays fully open and fully closed

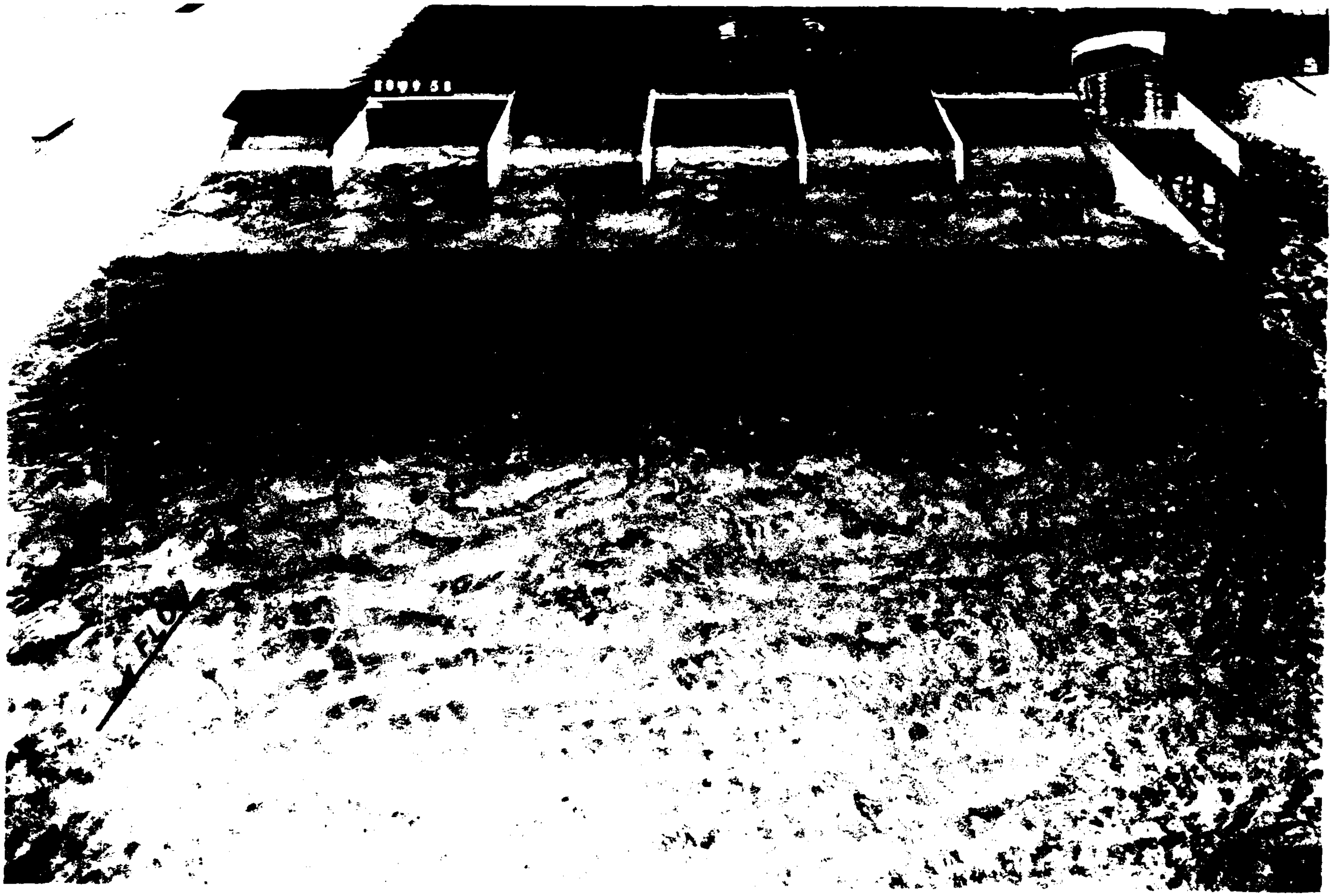


Photo 9. Submerged jump, alternate bays fully open and fully closed

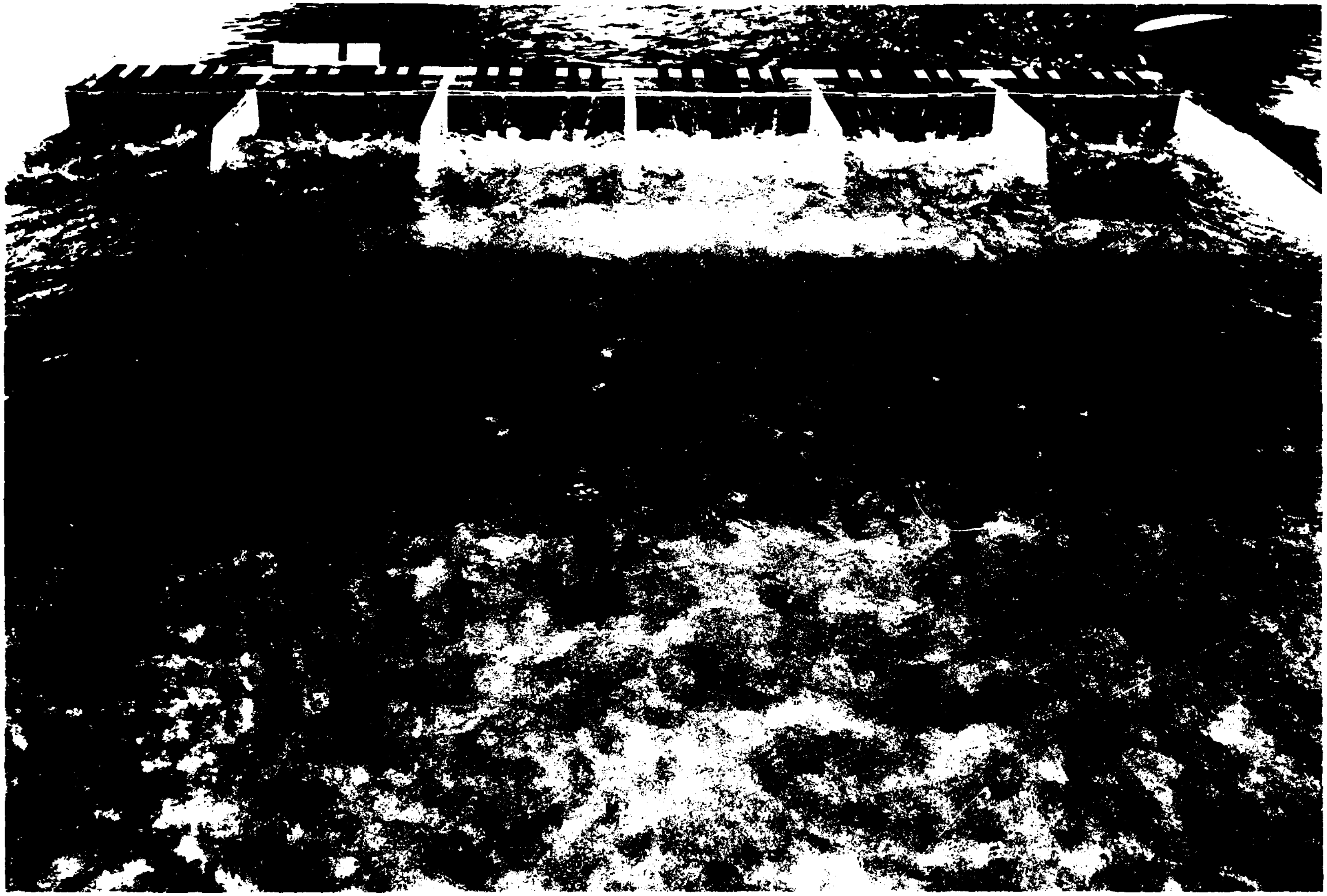


Photo 10. Stilling basin action with panel configuration 1, 46.7 percent opening per bay, headwater el 68.0, tailwater el 60.0

Photo 11. Stilling basin action with panel configuration 2, 46.7 percent opening per bay, headwater el 68.0, tailwater el 60.0

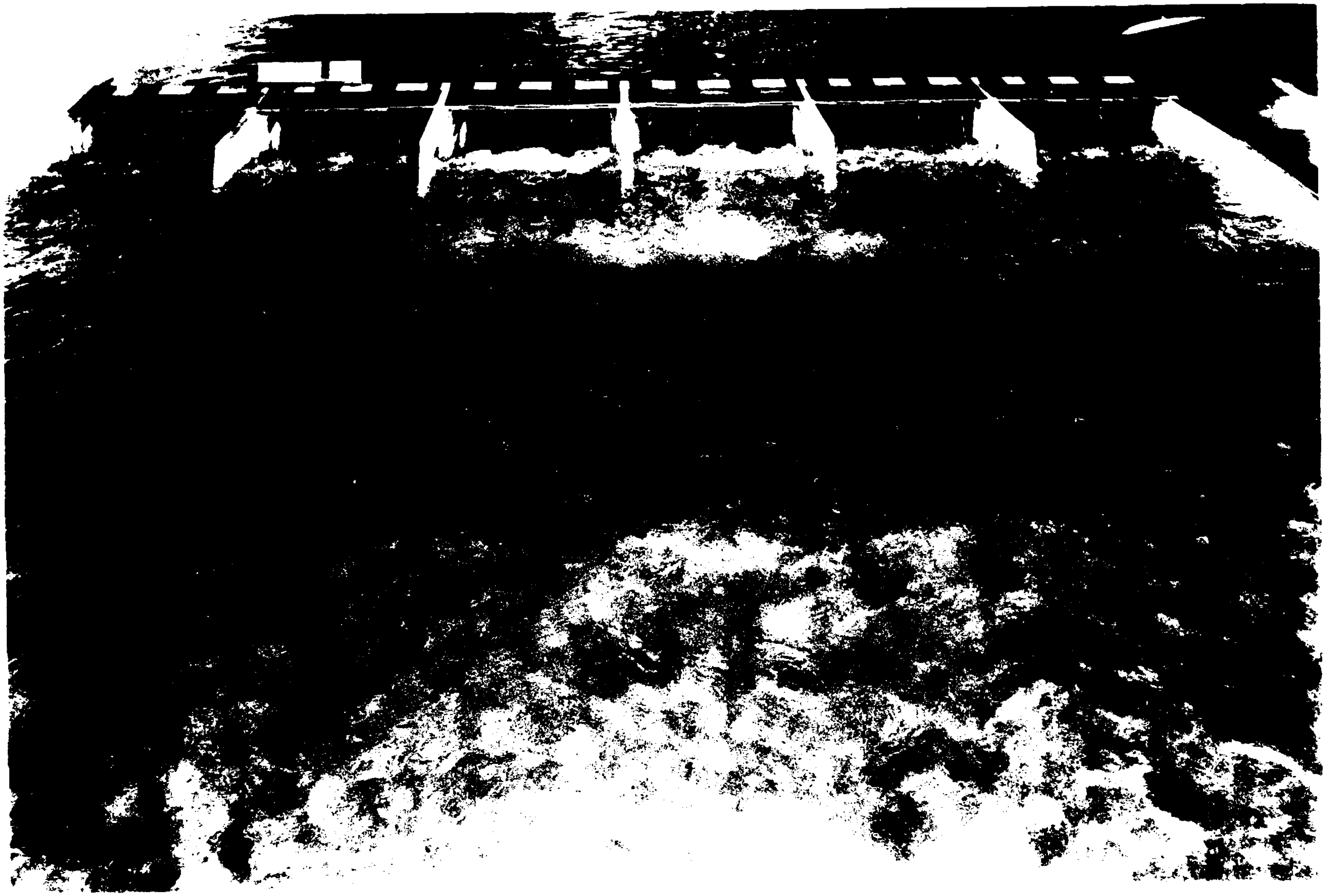


Photo 12. Stilling basin action with panel configuration 3, 46.7 percent opening per bay, headwater el 68.0, tailwater el 60.0

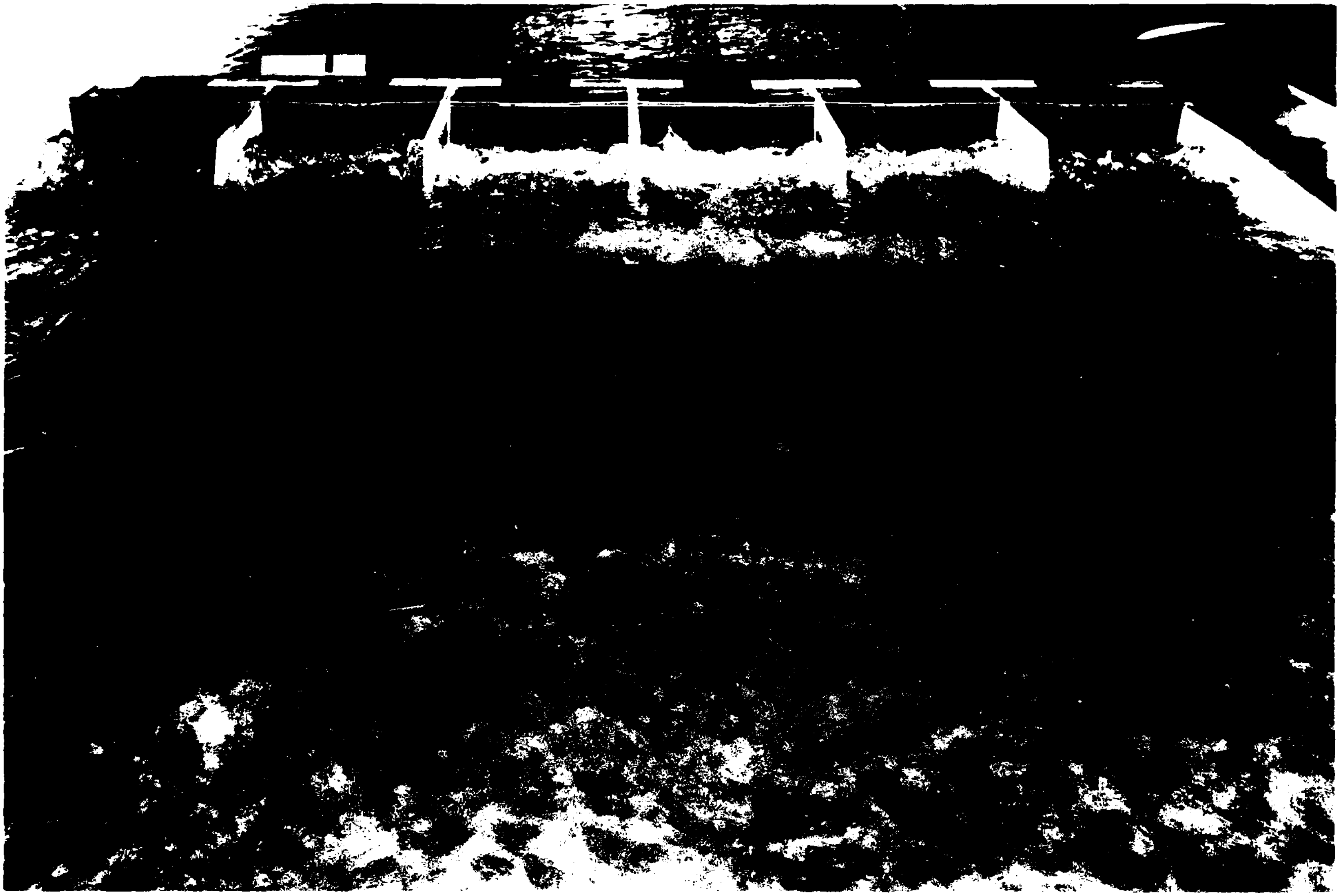


Photo 13. Stilling basin action with panel configuration 1, 40.0 percent opening per bay, headwater el 68.0, tailwater el 60.0

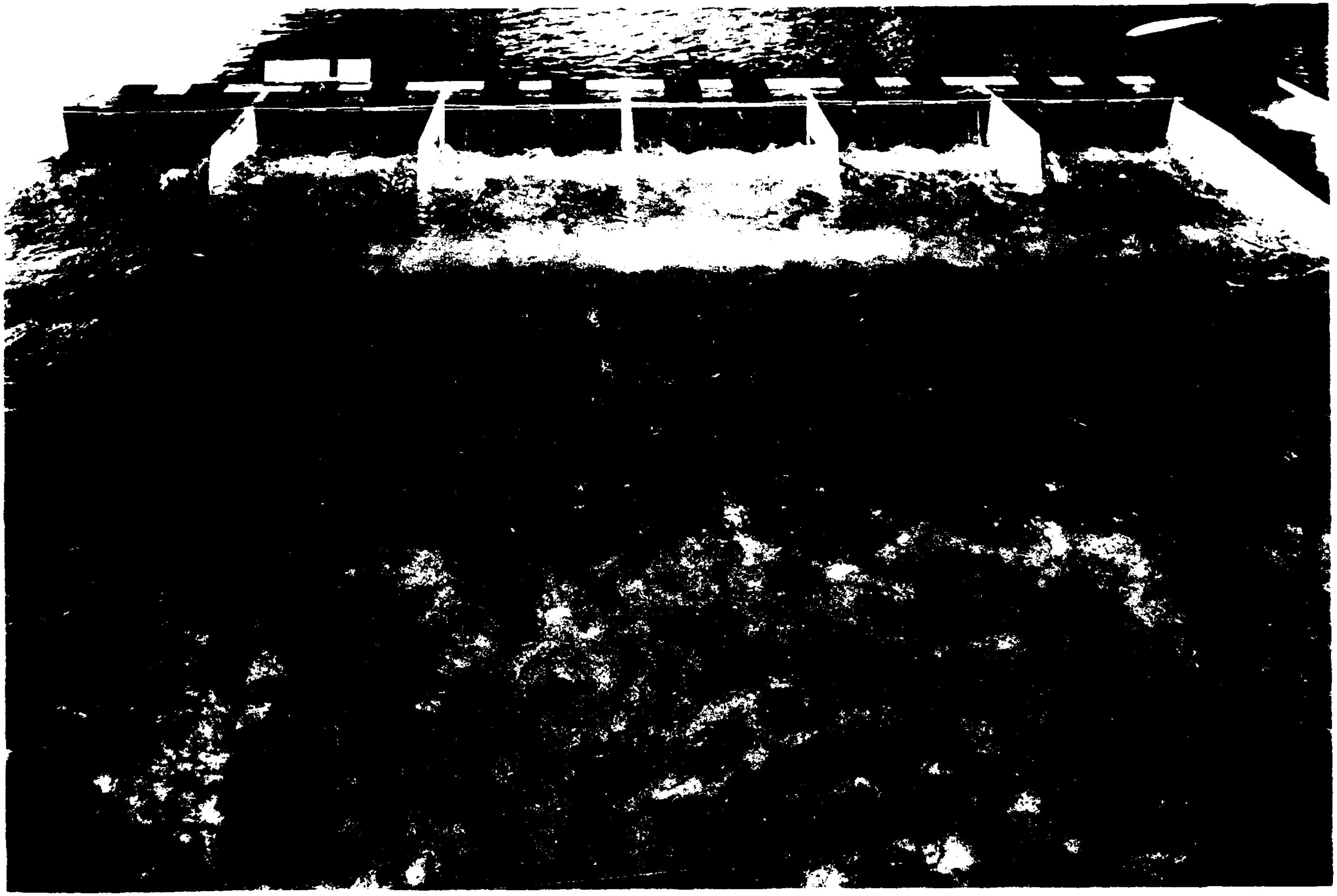


Photo 14. Stilling basin action with panel configuration 2, 40.0 percent opening per bay, headwater el 68.0, tailwater el 60.0

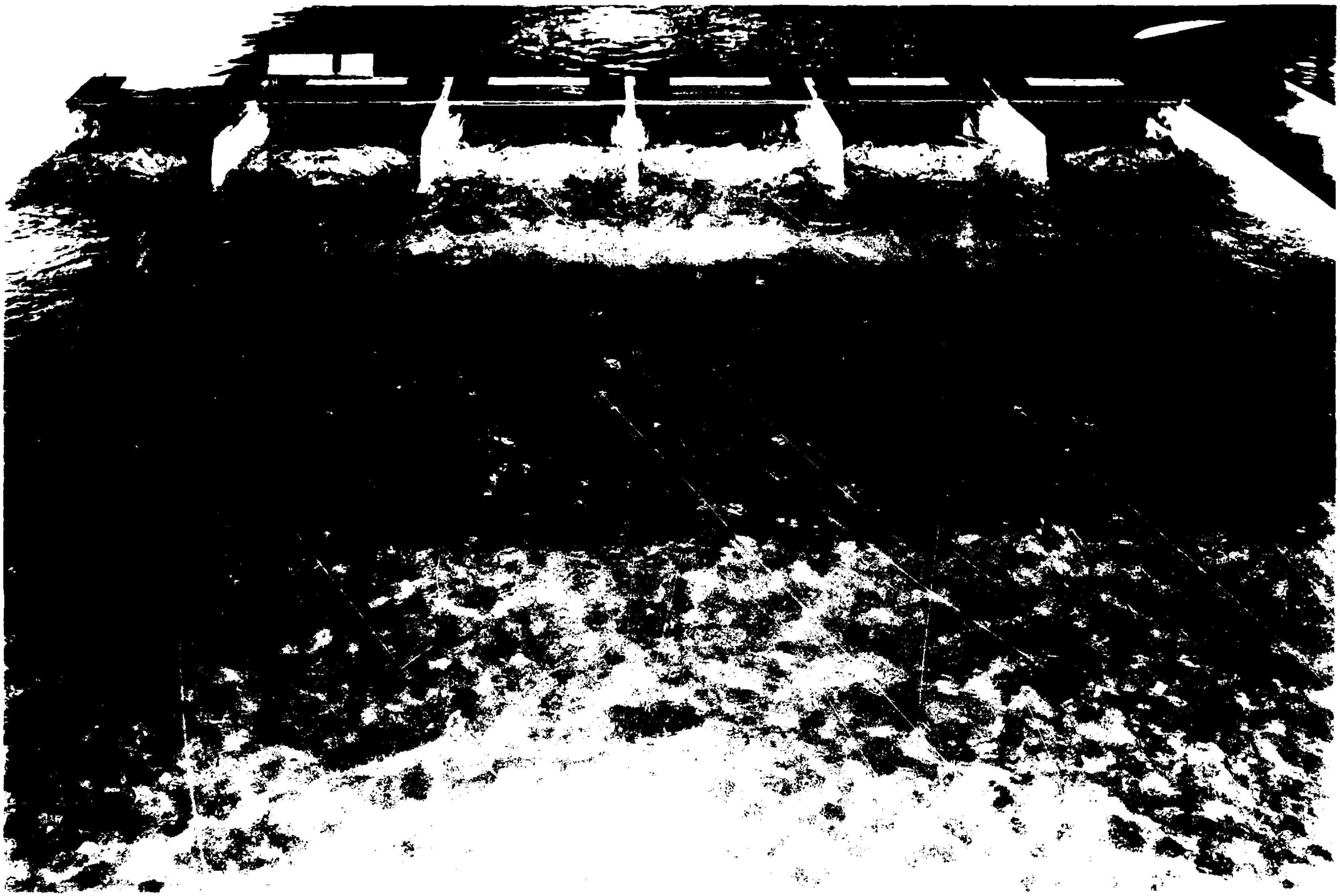


Photo 15. Stilling basin action with panel configuration 3, 40.0 percent opening per bay, headwater el 68.0, tailwater el 60.0

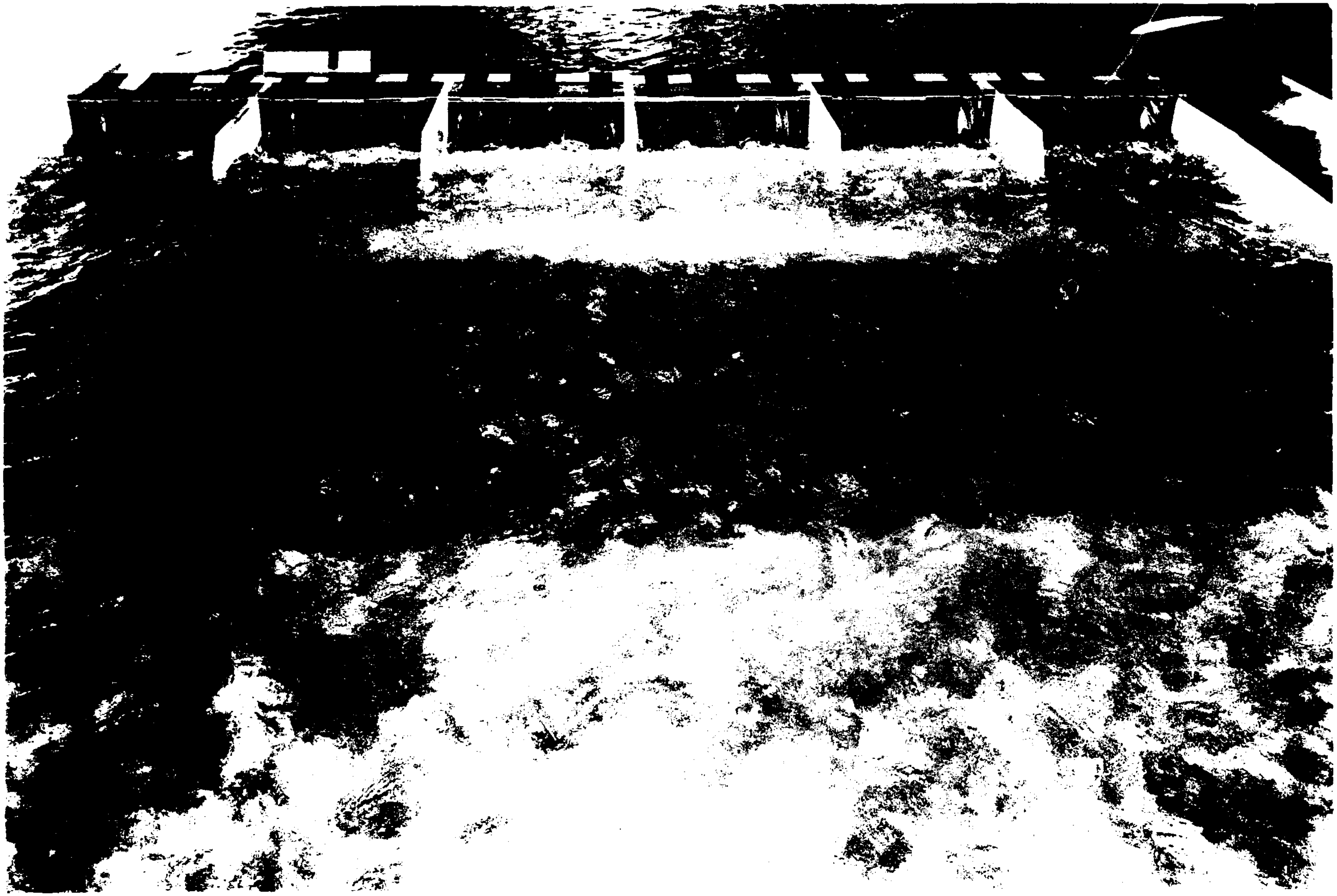


Photo 16. Stilling basin action with panel configuration 1, 53.3 percent opening per bay, headwater el 68.0, tailwater el 60.0

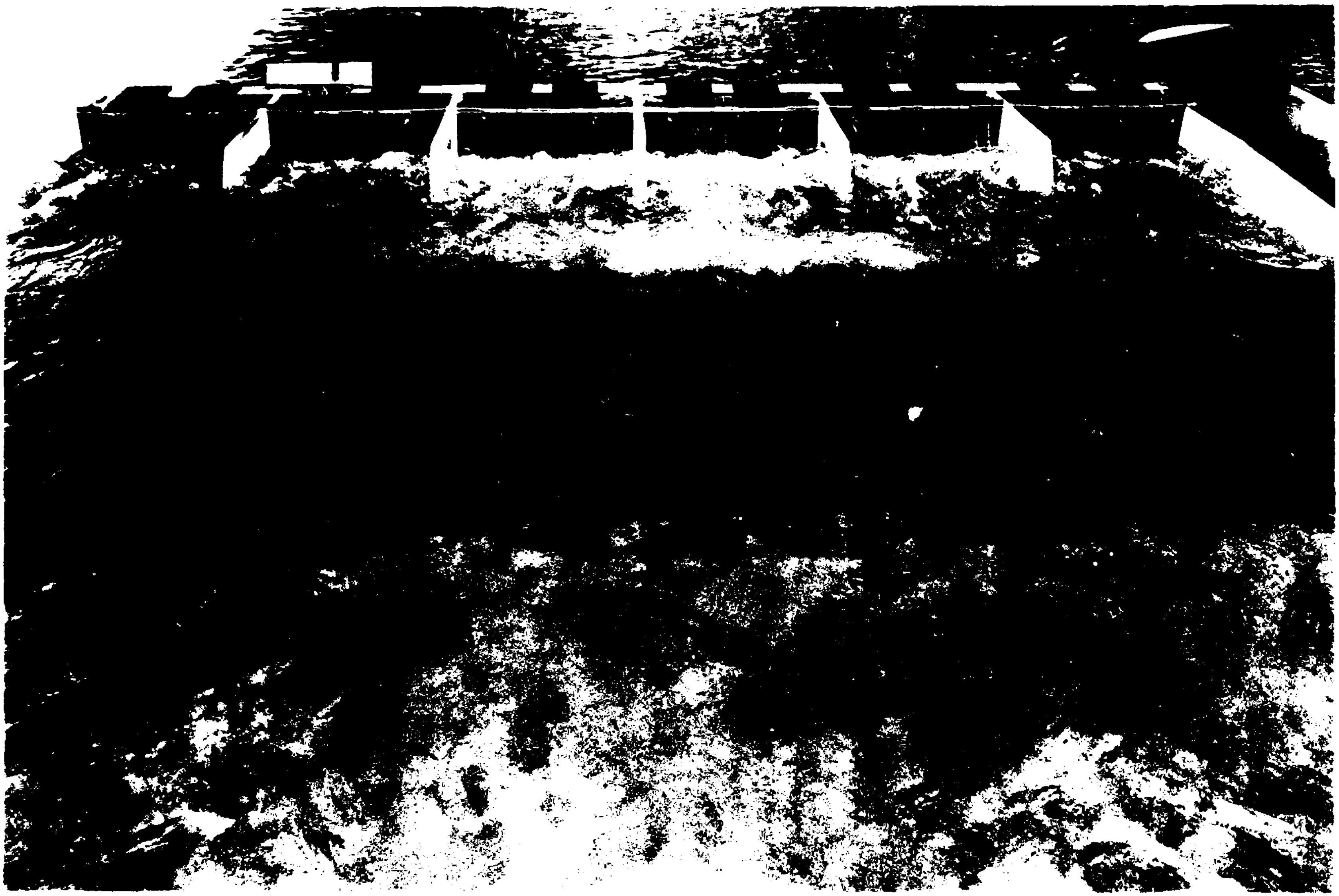


Photo 17. Stilling basin action with panel configuration 2, 53.3 percent opening per bay, headwater el 68.0, tailwater el 60.0

Photo 18. Stilling basin action with panel configuration 3, 53.3 percent opening per bay, headwater el 68.0, tailwater el 60.0

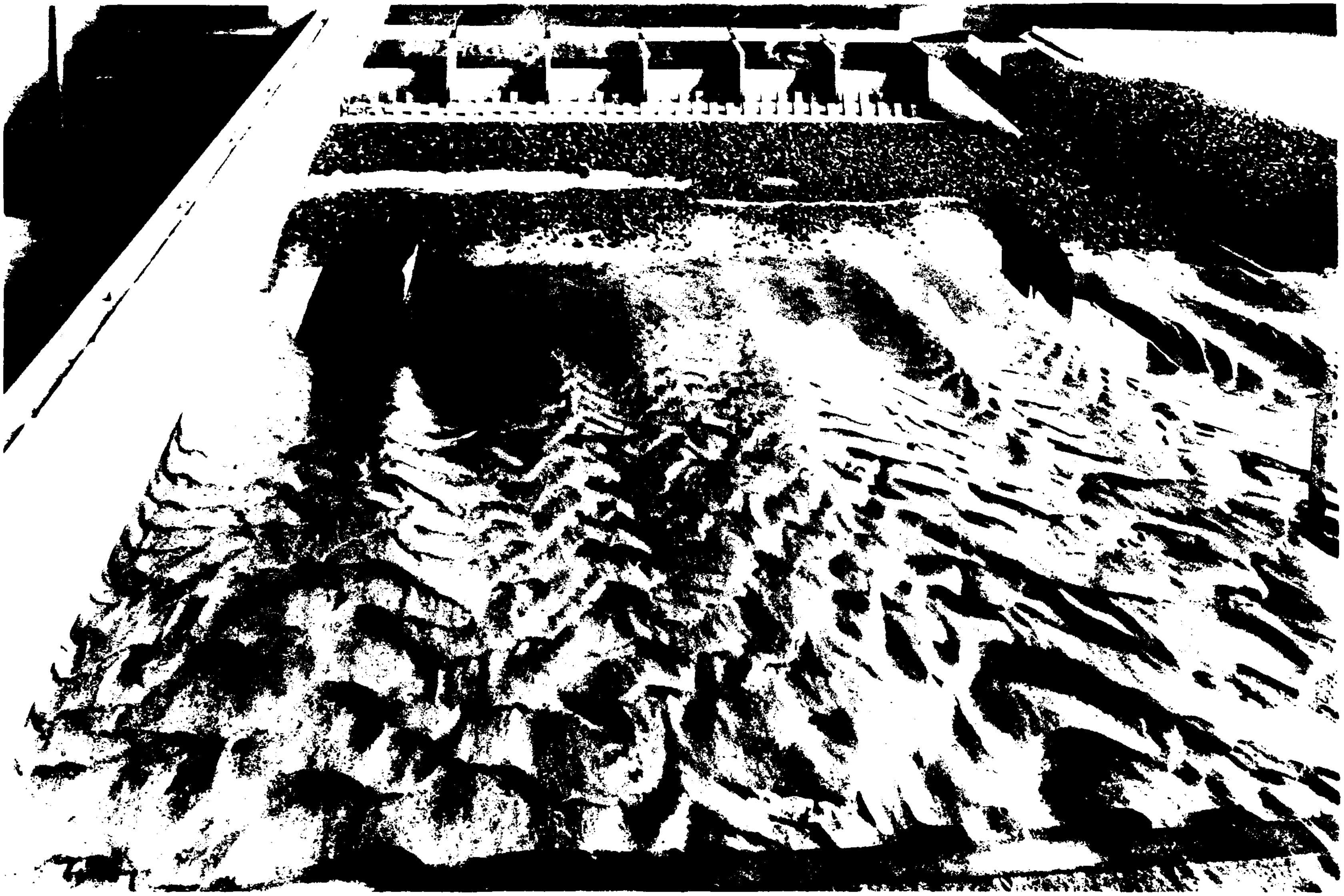


Photo 19. Areas of instability and scour potential, existing riprap, headwater el 62.0, tailwater el 52.0

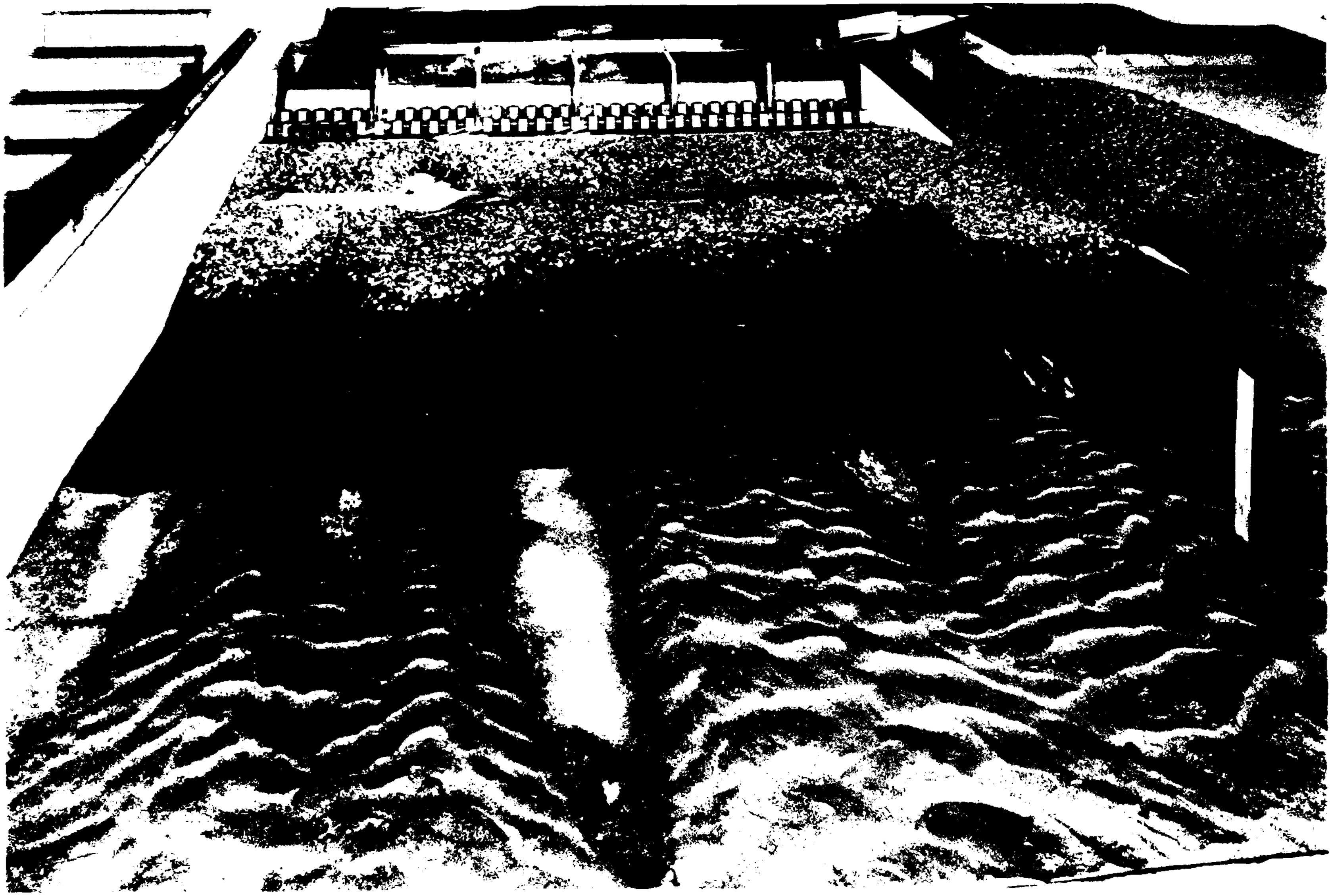


Photo 20. Areas of instability and scour potential, existing riprap, headwater el 64.0, tailwater el 54.0

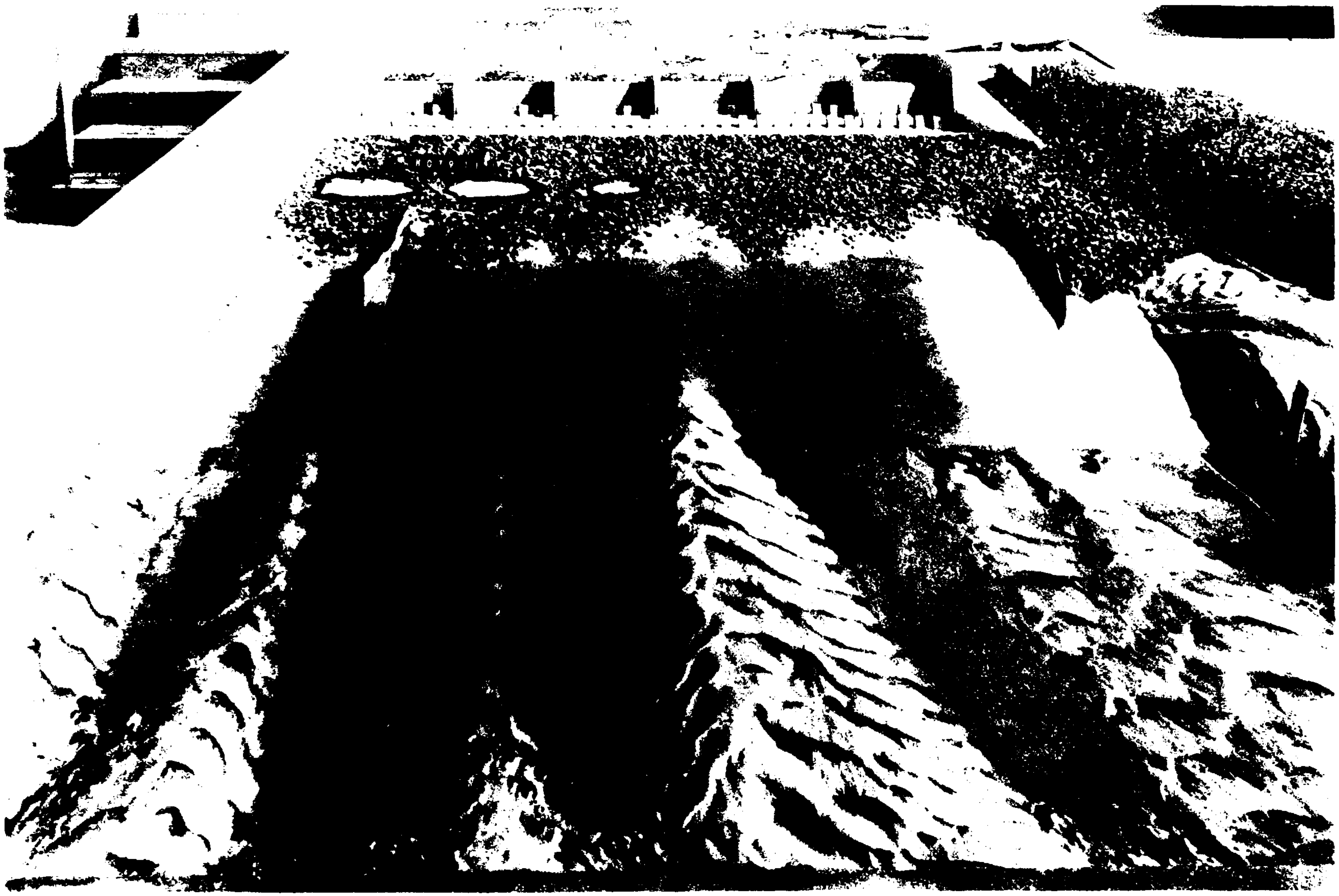


Photo 21. Areas of instability and scour potential, existing riprap, headwater el 65.0, tailwater el 56.0

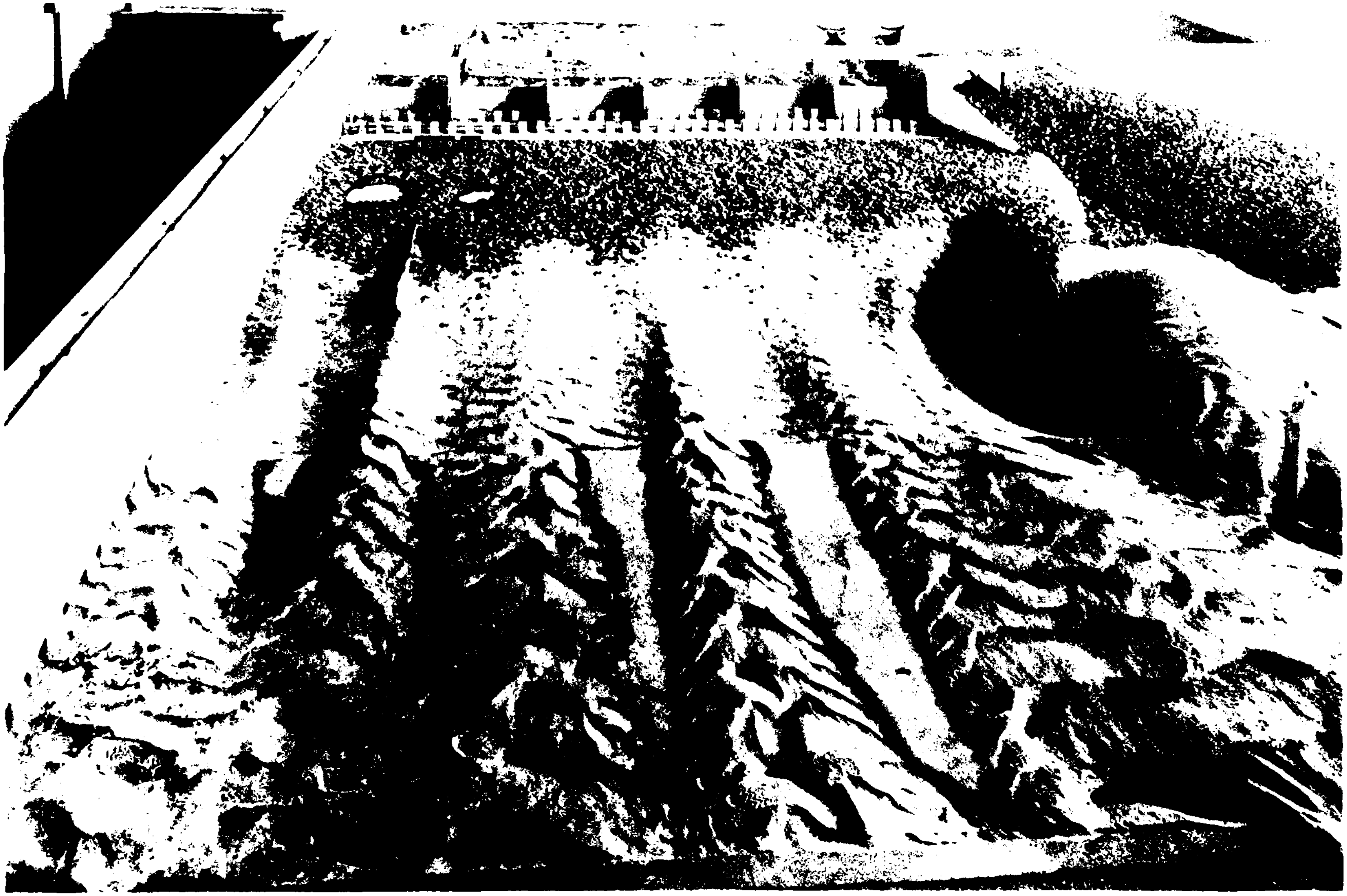


Photo 22. Areas of instability and scour potential, existing riprap, headwater el 66.0, tailwater el 59.0

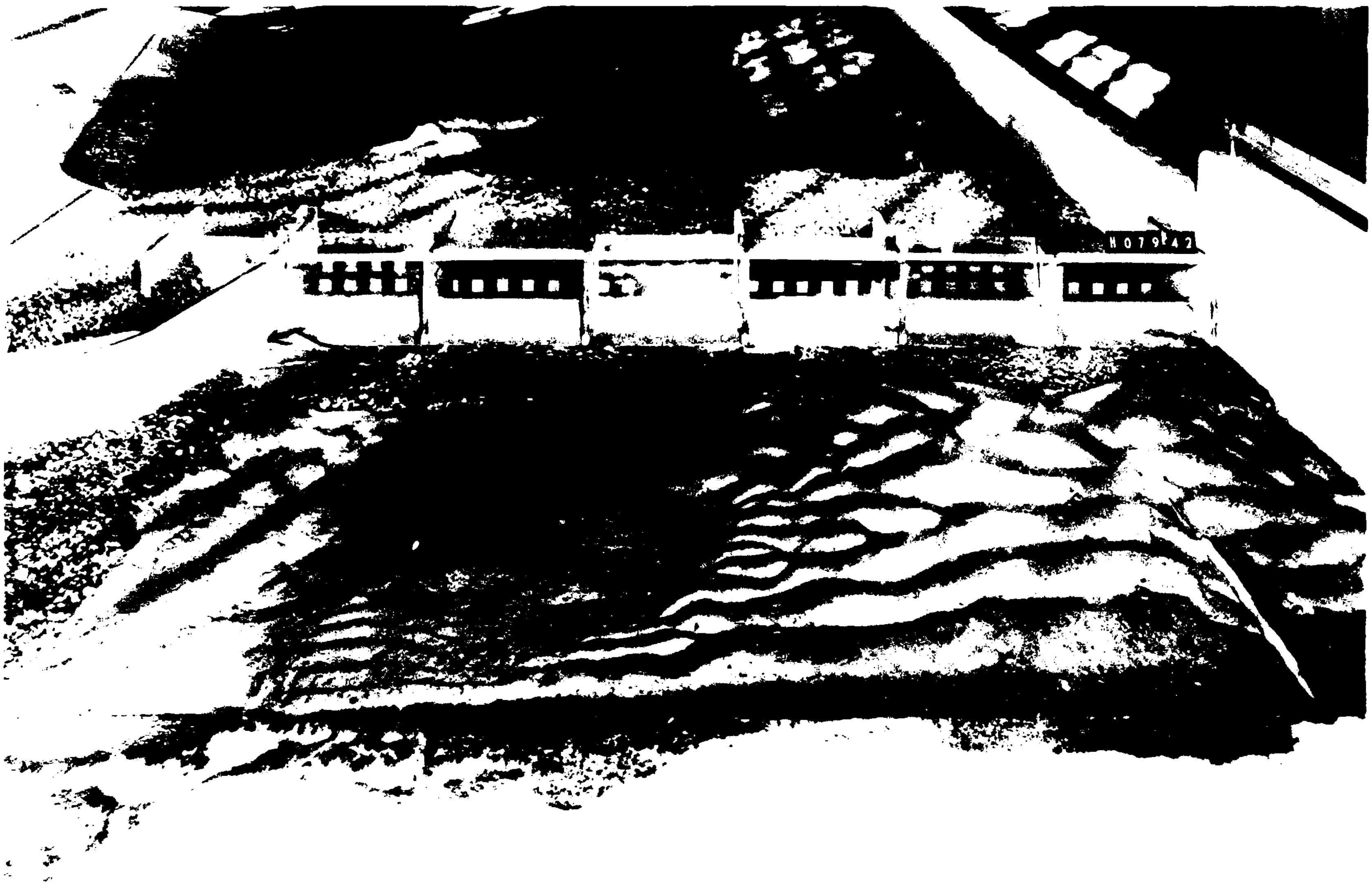


Photo 23. Areas of instability and scour potential, existing riprap, alternate bays fully open and closed, headwater el 67.0, tailwater el 55.0

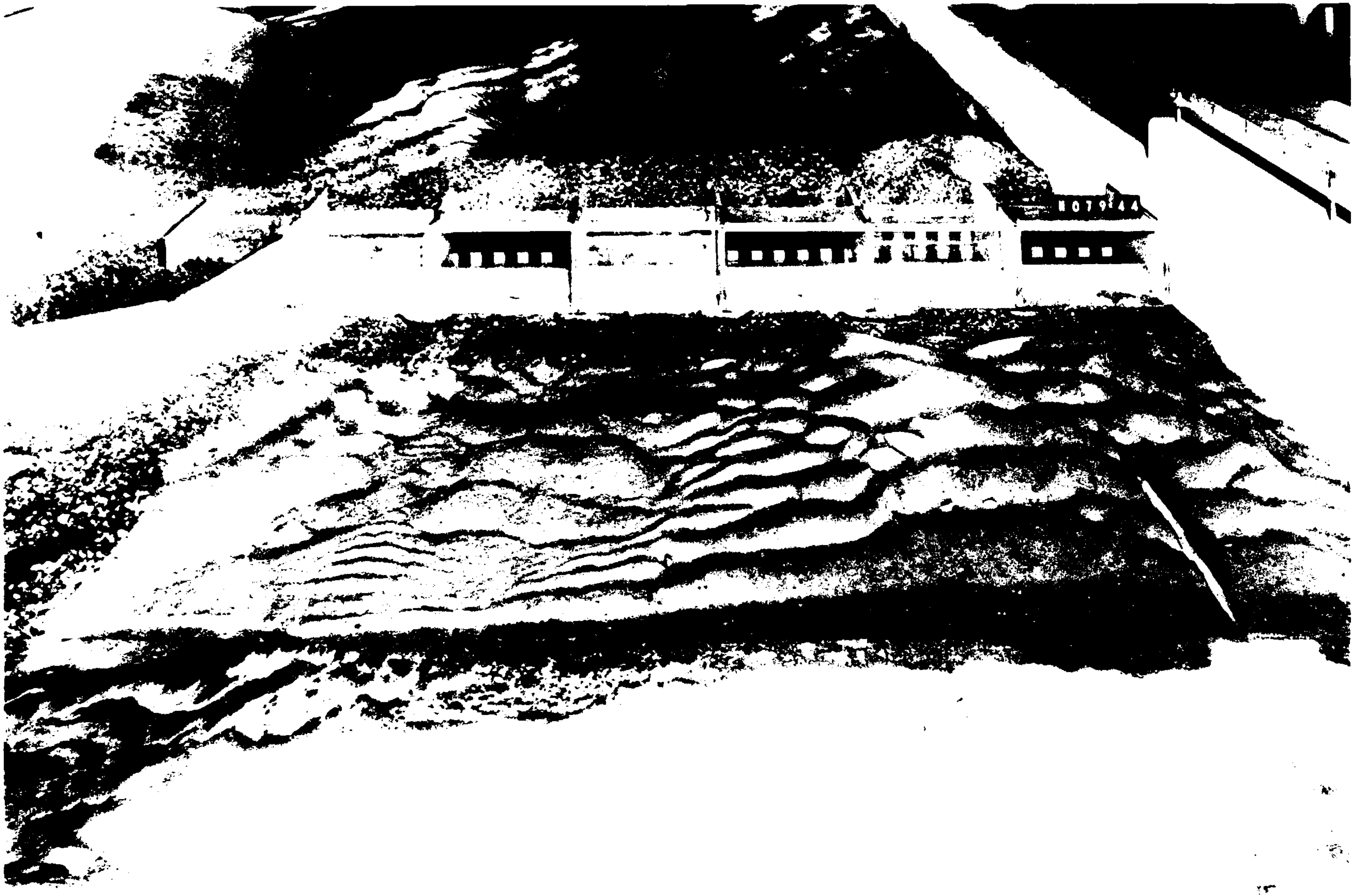


Photo 24. Areas of instability and scour potential, existing riprap, alternate bays fully open and closed, headwater el 68.0, tailwater el 56.0

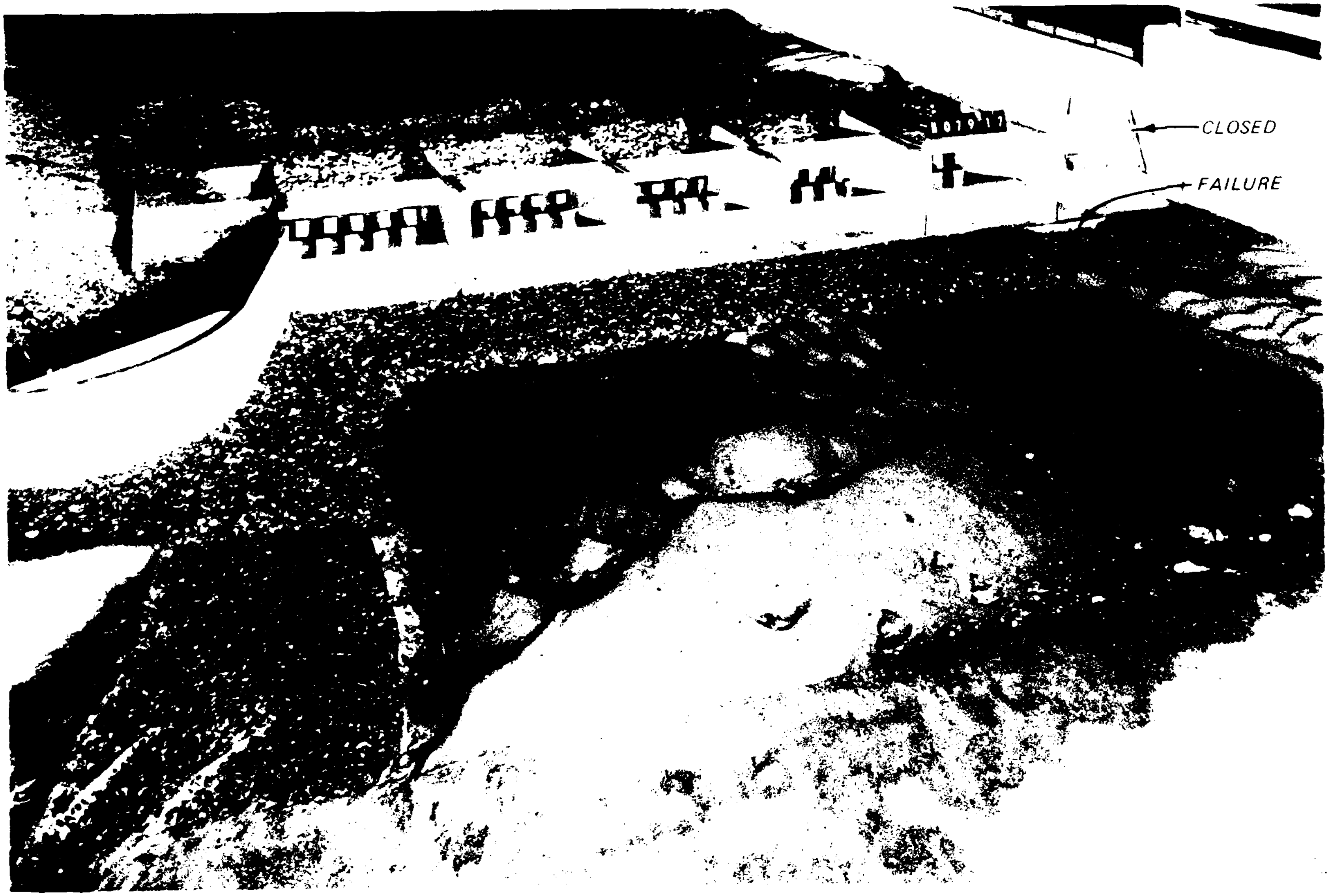


Photo 25. Areas of instability and scour potential, existing upstream riprap, five consecutive bays fully open, headwater el 68.0, tailwater el 56.0

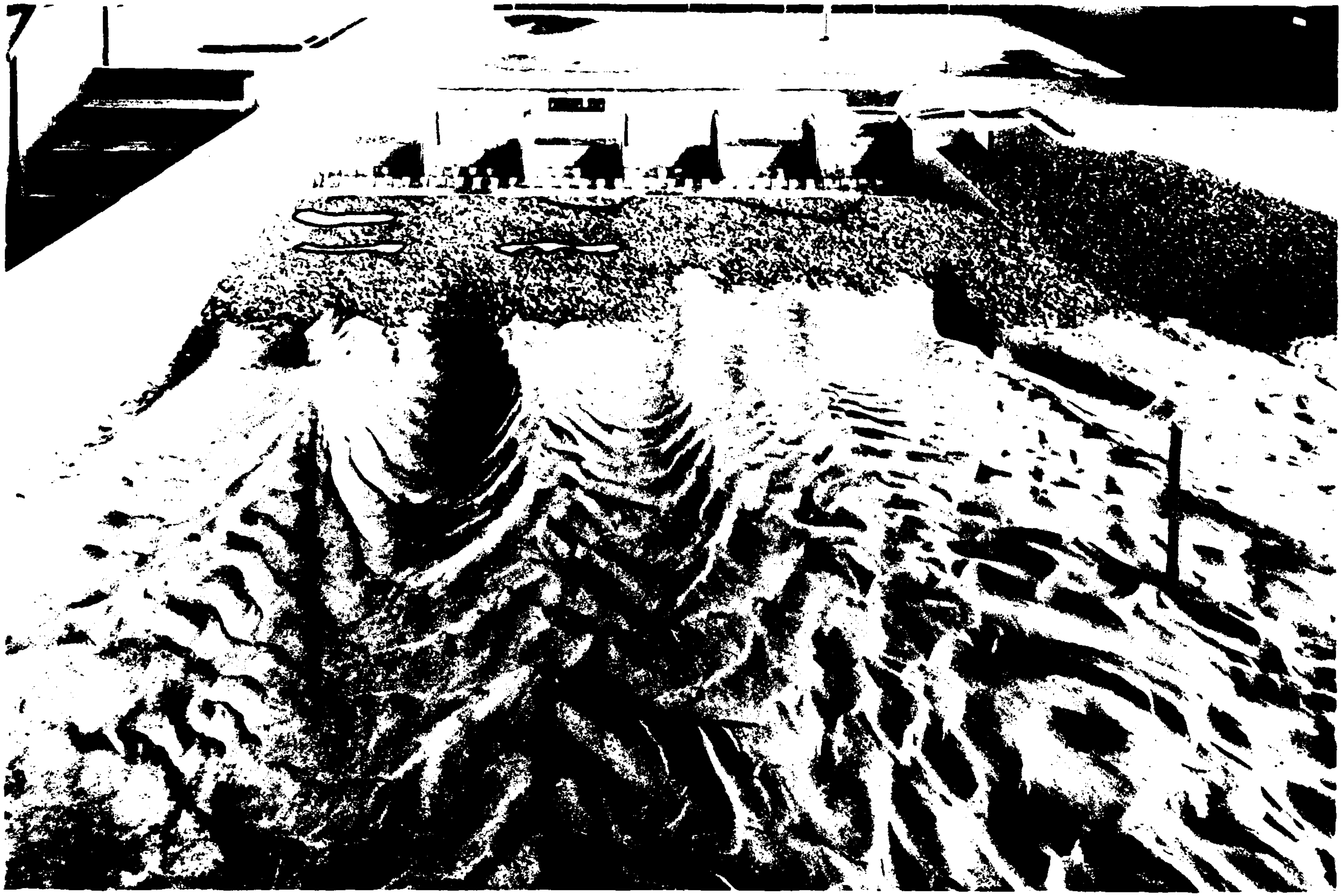


Photo 26. Areas of instability and scour potential, existing riprap downstream of the structure, alternate gate bays fully open and closed, headwater el 65.0, tailwater el 54.0

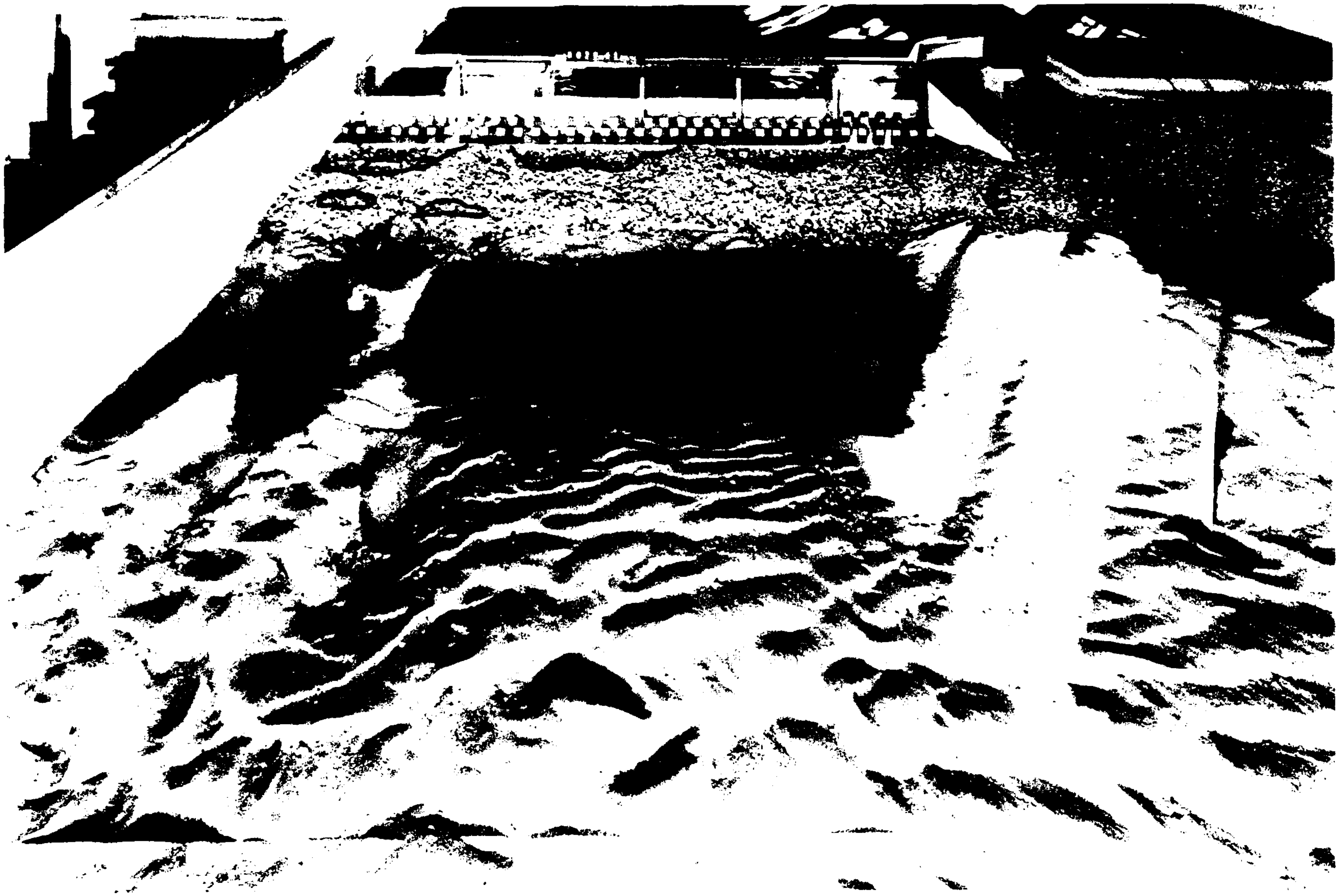


Photo 27. Areas of instability and scour potential, existing riprap downstream of the structure, alternate gate bays fully open and closed, headwater el 67.0, tailwater el 55.0

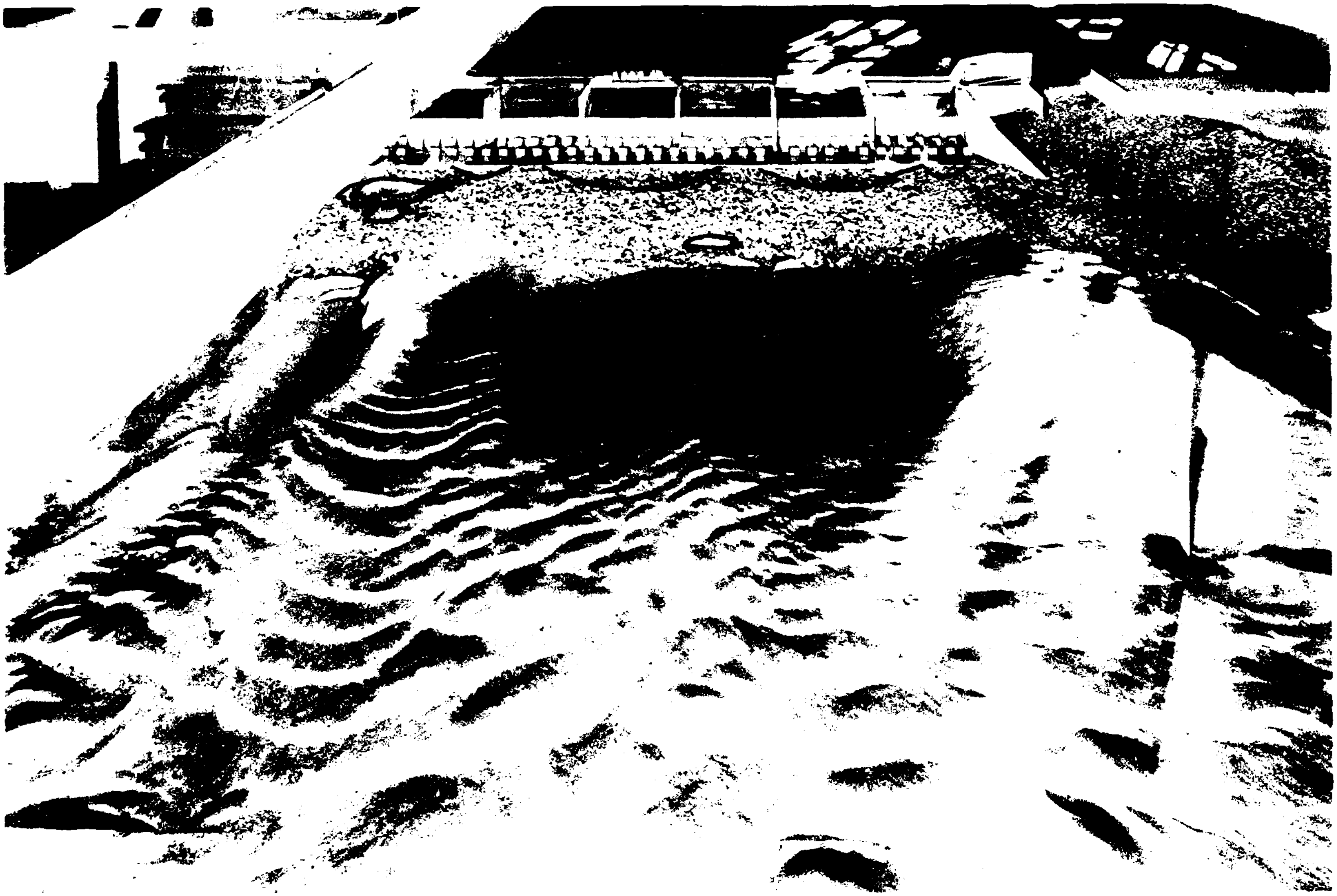


Photo 28. Areas of instability and scour potential, existing riprap downstream of the structure, alternate gate bays fully open and closed, headwater el 68.0, tailwater el 56.0

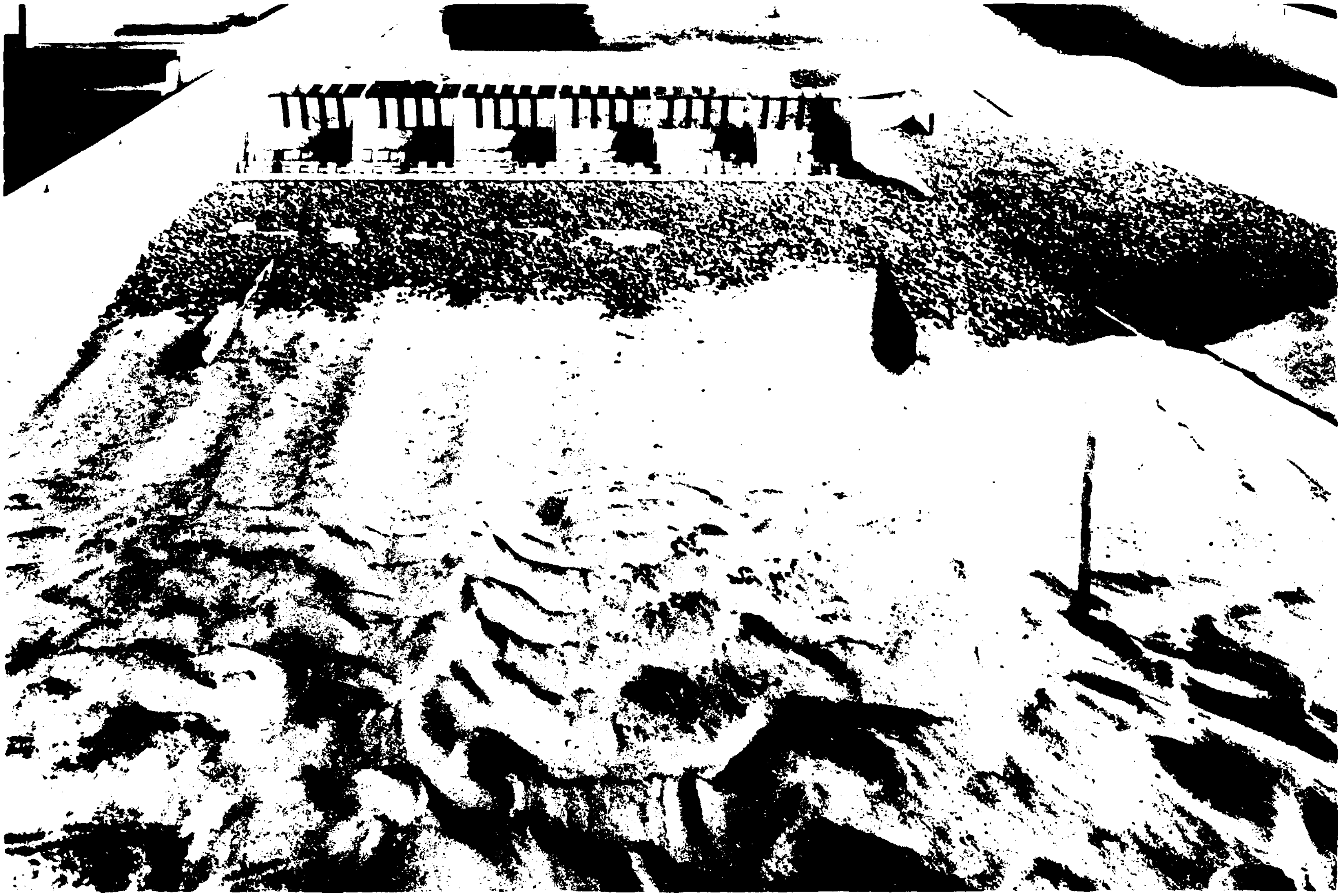
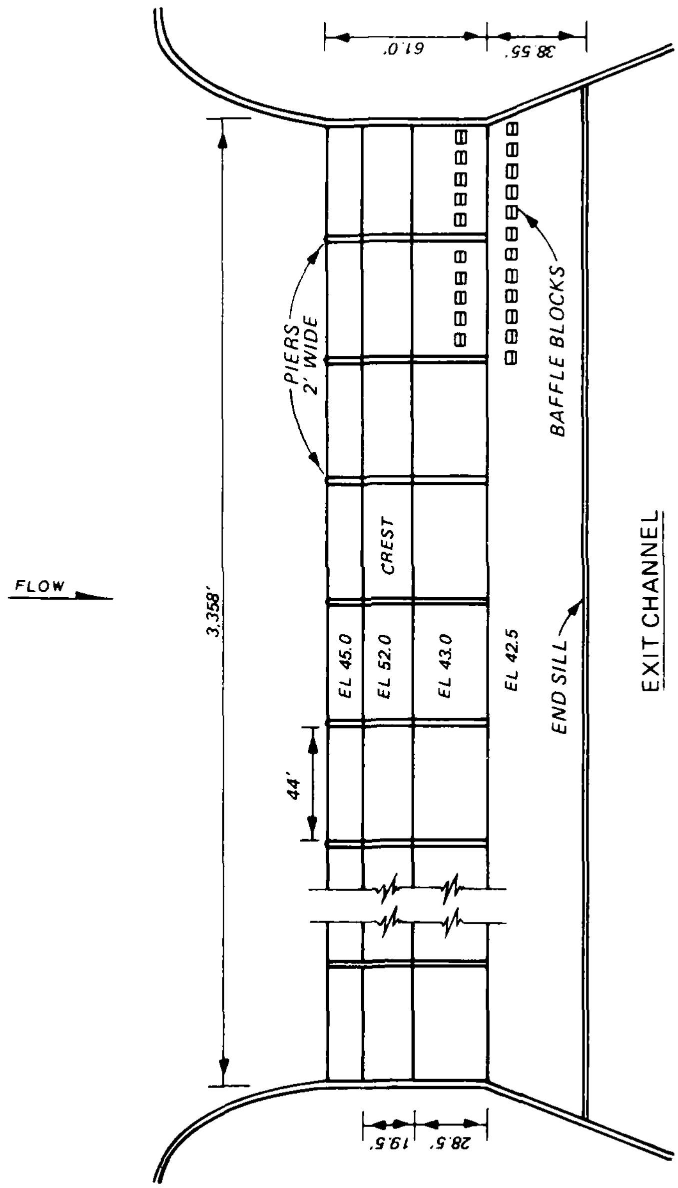
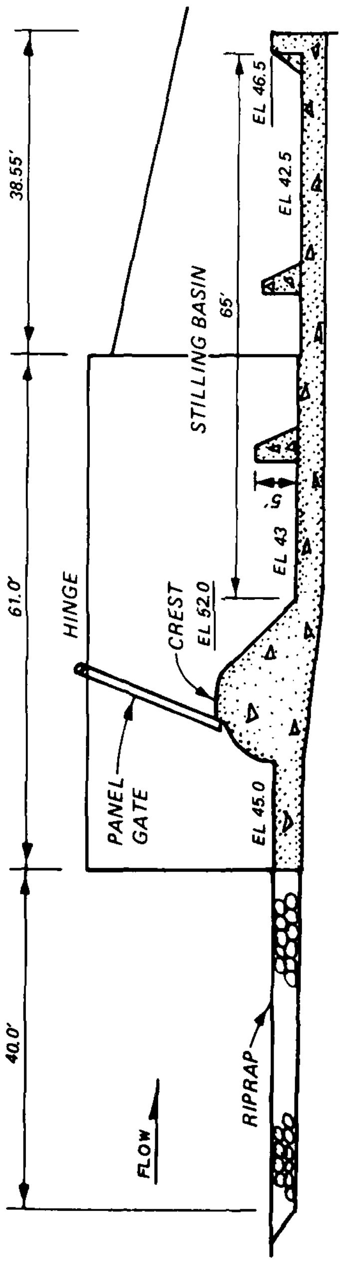


Photo 29. Failure of existing downstream riprap protection, 73.7 percent opening per bay, 11 open and 4 closed timber panels, headwater el 68.0, tailwater el 55.0

Photo 30. Prototype structure open 53.3 percent during 1983 release

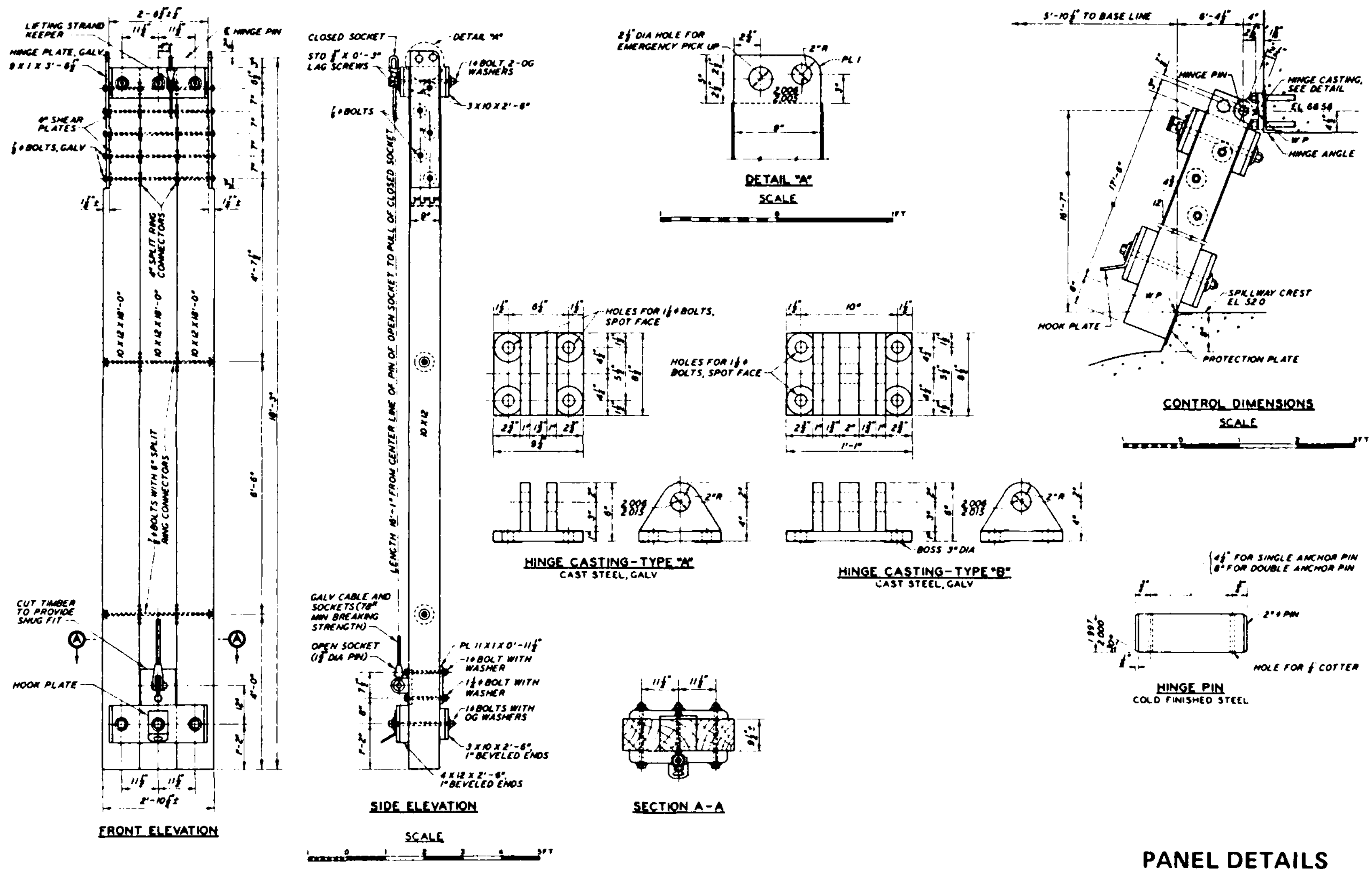


PLAN OF
OVERBANK STRUCTURE



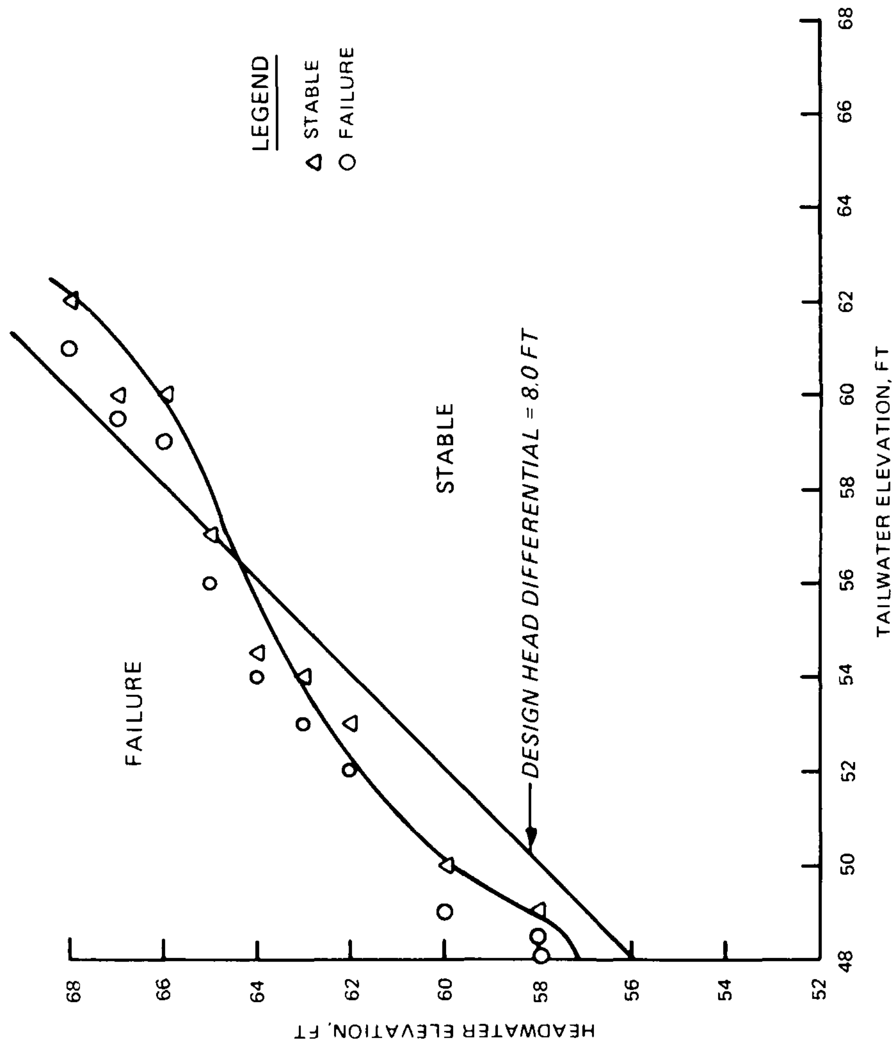
ELEVATION OF
OVERBANK STRUCTURE

PLATE 2

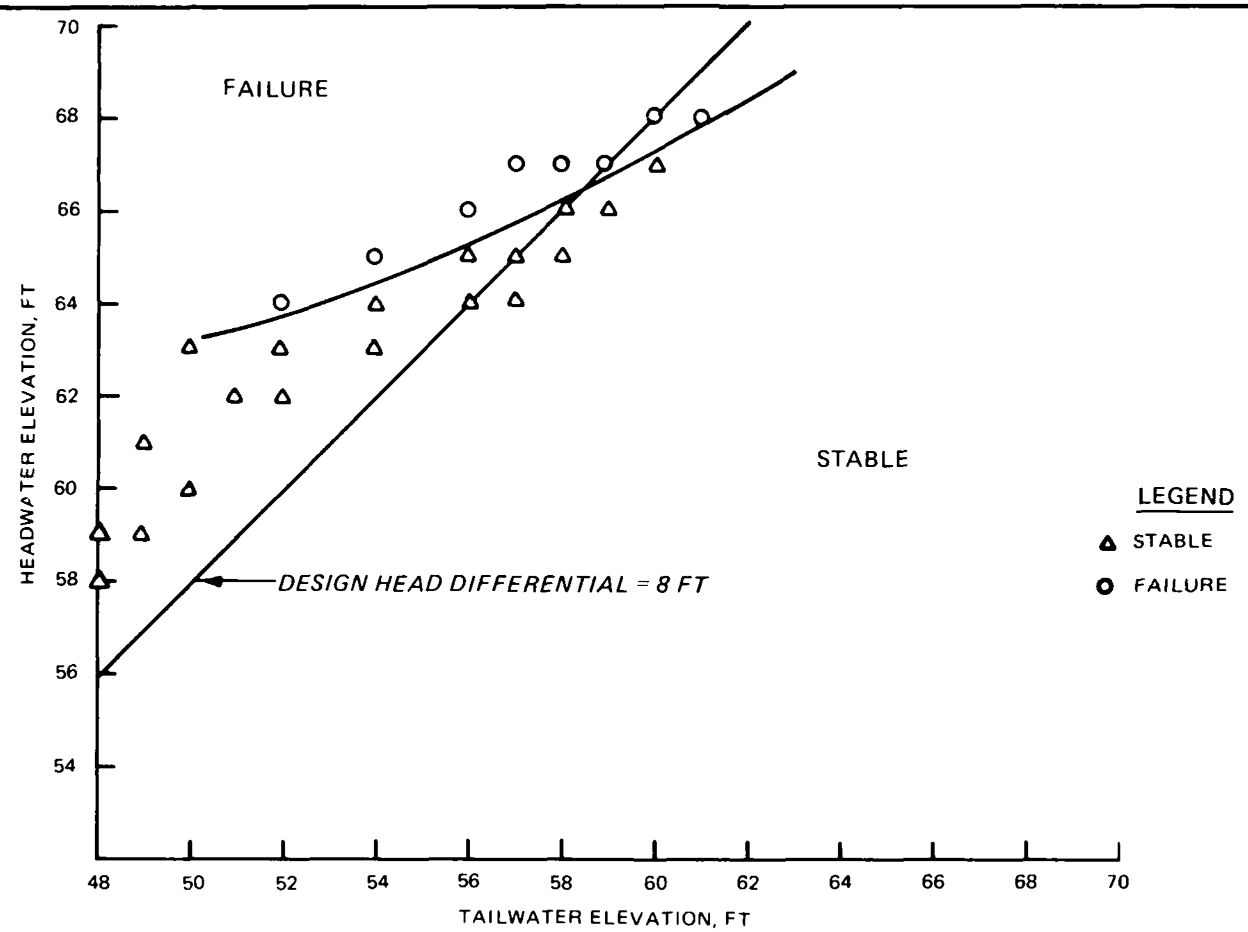


PANEL DETAILS

From TR 2-491, US Army Engineer Waterways Experiment Station 1959.

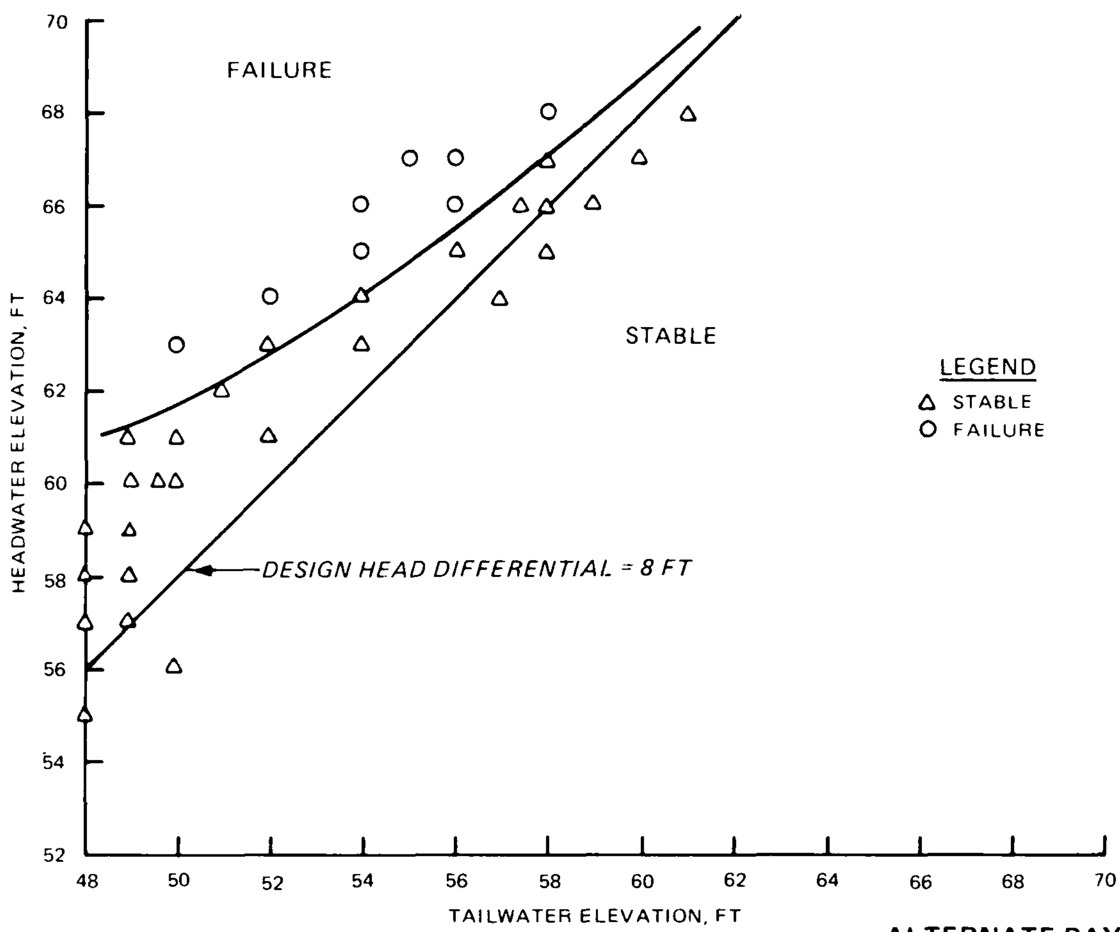


CONSECUTIVE BAYS FULLY OPEN
STABILITY OF EXISTING DOWNSTREAM RIPRAP PROTECTION



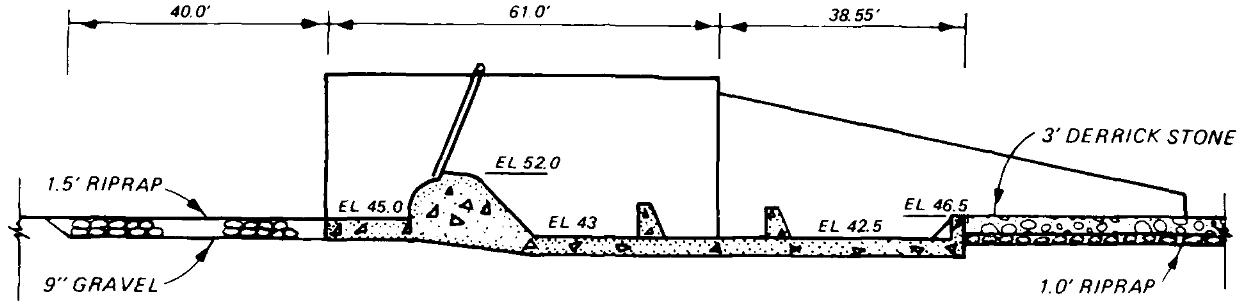
NOTE: STAGGERED GATE OPERATIONS

ALTERNATE BAYS FULLY OPEN AND FULLY CLOSED
STABILITY OF EXISTING UPSTREAM RIPRAP PROTECTION



NOTE: STAGGERED GATE OPERATIONS

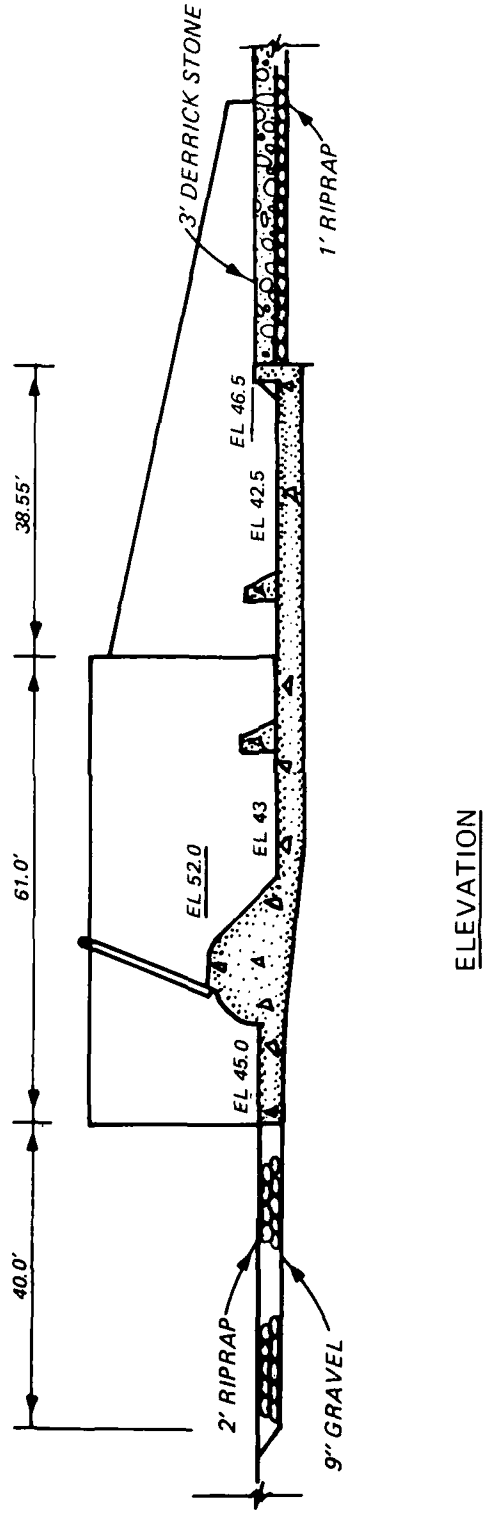
ALTERNATE BAYS FULLY OPEN AND FULLY CLOSED STABILITY OF EXISTING DOWNSTREAM RIPRAP PROTECTION

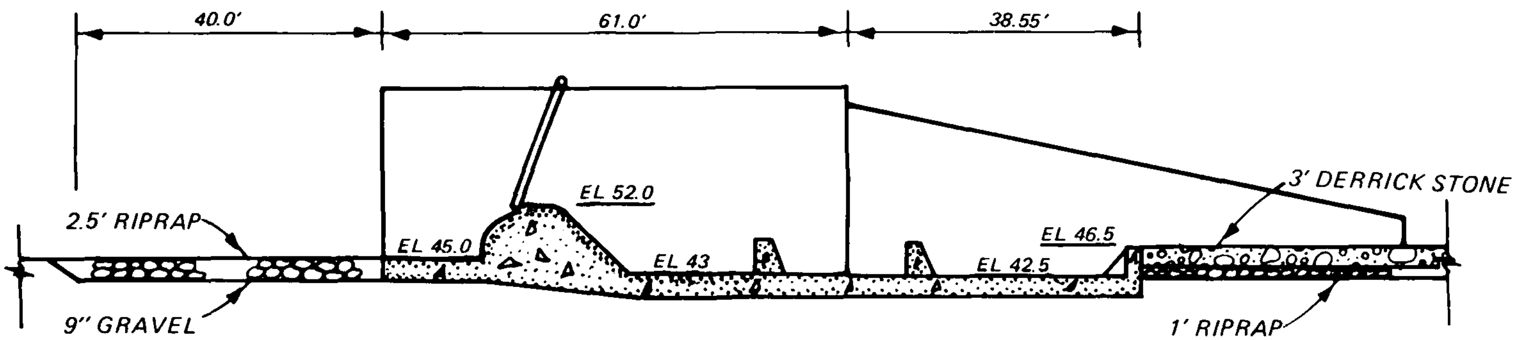


ELEVATION

ORIGINAL RIPRAP PROTECTION
PLAN 1 - UPSTREAM

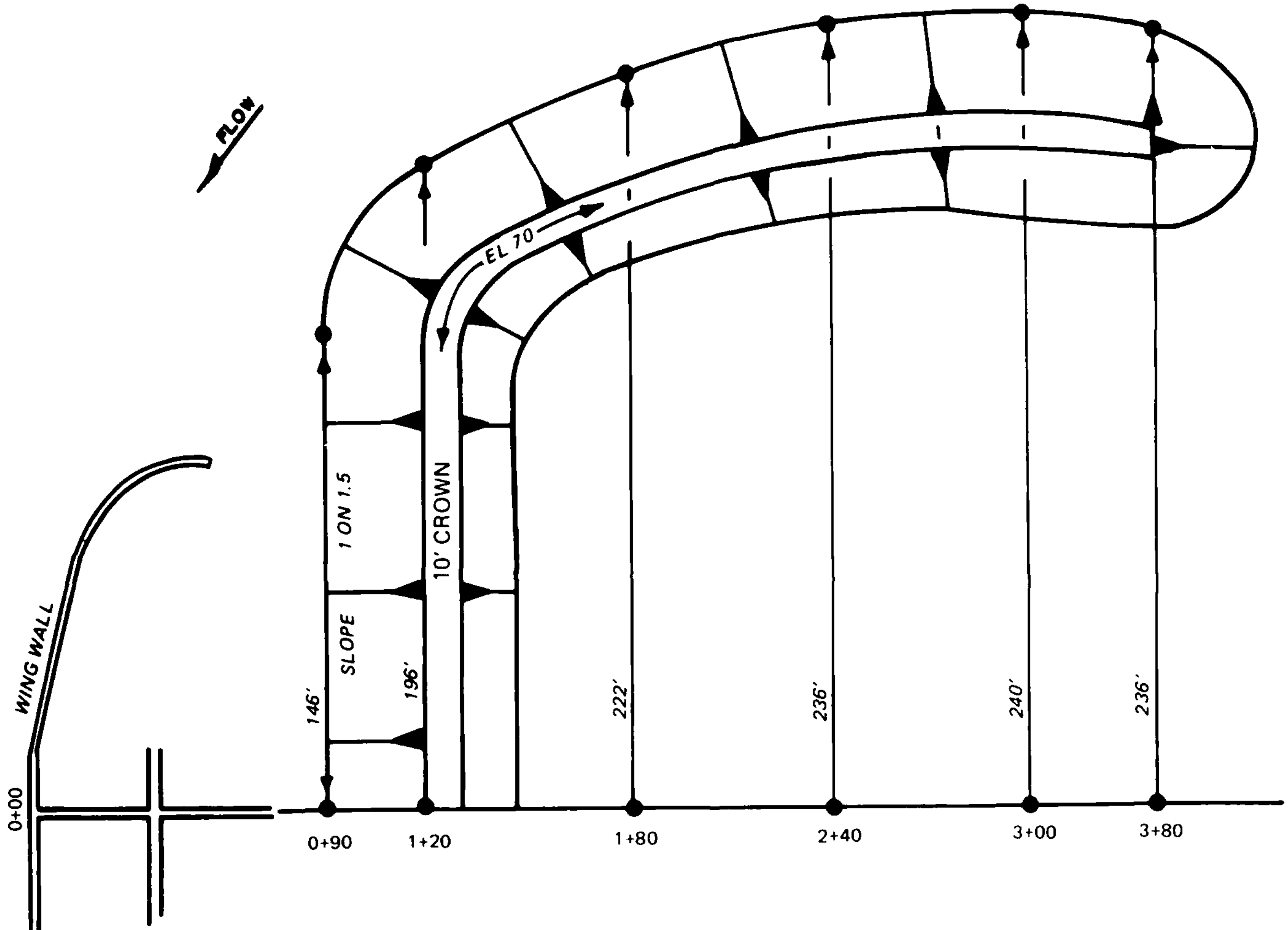
RIPRAP PROTECTION
PLAN 2 – UPSTREAM





ELEVATION

RIPRAP PROTECTION
PLAN 3 - UPSTREAM



LOCATION OF RIPRAP DIKE AT SOUTH END OF OVERBANK STRUCTURE

END
DATE
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